Universidade de Lisboa
Faculdade de Motricidade Humana

DEVELOPMENT OF MOTOR COMPETENCE IN CHILDHOOD AND ADOLESCENCE

Dissertação elaborada com vista à obtenção do Grau de Doutor em Motricidade Humana, especialidade de Comportamento Motor

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Carlos Miguel Nunes da Luz

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To my family and friends.

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Abstract

This dissertation aimed to investigate the development of motor competence in childhood and adolescence. As a starting point, a systematic review was conducted to investigate the instruments used for the evaluation of motor competence. This review identified a gap in the literature regarding the existence of an instrument to assess motor competence based on the three theoretical constructs (stability, locomotor, manipulative). In an attempt to fill this gap, a valid quantitative instrument was proposed. To meet this purpose, 584 children, between 6 and 14 years of age, were evaluated in nine motor tasks, three for each construct. The final instrument comprised two motor tasks for each construct (stability, locomotor, manipulative) and presented very good fit indexes. This instrument was used to analyse the motor competence behaviour by gender in different age groups, indicating that generally boys outperformed girls and both genders increased their performance across age groups. However, different motor competence growth rates appear in both genders across age groups. In addition, children with high and low motor competence were compared regarding some of their health related fitness variables. We found that, regardless of age and gender, the group with better motor proficiency always showed better results in health related fitness. We found positive moderate to high correlations between motor competence and the variables of cardiovascular fitness and muscular fitness, and an inverse correlation with body composition across the four age groups. We also found that motor competence explained 75% of the variance of the health related fitness for the total sample, with locomotion as the primary predictor. However, when analysing the four age groups, stability skills seem to play an important role in health related fitness in the transition from childhood to adolescence. In conclusion, educational and health policies should consider the development of motor competence as an essential strategy to promote healthy development throughout life.

Keywords

Children, adolescents, motor competence, health related fitness, high motor competence, low motor competence.

Resumo

Esta tese teve como objetivo investigar o desenvolvimento da competência motora na infância e adolescência. Inicialmente, foi realizada uma revisão sistemática para investigar os instrumentos utilizados para avaliar a competência motora. Esta revisão identificou uma lacuna na literatura relativa à existência de um instrumento que avalie a competência motora com base nos três constructos teóricos (estabilização, locomoção e manipulação). Na tentativa de colmatar essa lacuna foi proposto um instrumento quantitativo válido. Nesse sentido, 584 crianças (300 rapazes), com idades entre os 6 e os 14 anos (M=10.60, DP=2.40) foram avaliadas em nove tarefas motoras, três de cada constructo. O instrumento final apresentou duas tarefas de cada constructo com muito bons índices de ajuste, tendo sido utilizado para analisar o comportamento da competência motora por género e em diferentes grupos de idade. Os resultados indicam que, geralmente, os rapazes superam as raparigas e que ambos os géneros aumentam a sua performance entre os grupos etários. No entanto, rapazes e raparigas apresentam taxas de crescimento da competência motora diferenciadas. Adicionalmente, crianças com alta e baixa competência motora foram comparadas, no que concerne às variáveis de aptidão física. Verificámos que, independente da faixa etária e do género, o grupo com melhor proficiência motora apresentou resultados superiores nas variáveis de aptidão física. Encontrámos correlações positivas moderadas a elevadas entre a competência motora e as variáveis de aptidão cardiovascular e muscular e correlações inversas com a composição corporal nos diferentes grupos de idade. Encontrámos correlações moderadas a elevadas entre a competência motora e as variáveis de aptidão cardiovascular e muscular e inversas com a composição corporal ao longo dos quatro grupos etários. Apurámos ainda que a competência motora explica 75% da variância da aptidão física para a amostra total, com a locomoção como principal preditor. No entanto, analisando os quatro grupos etários parece que as habilidades estabilizadoras podem desempenhar um papel importante na aptidão física na transição da infância para a adolescência. Em conclusão, as políticas educativas e de saúde devem considerar o desenvolvimentos da competência motora como estratégia essencial para promover um desenvolvimento saudável ao longo da vida.

Palavras-chave

Crianças, adolescentes, competência motora, indicadores de aptidão física relacionados com a saúde, alta proficiência motora, baixa proficiência motora.

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Abbreviations

BMI	-	**B**ody **M**ass **I**ndex
BOTMP	-	**B**ruininks-**O**seretsky **T**est of **M**otor **P**roficiency
BOT-2	-	**B**ruininks-**O**seretsky **T**est of **M**otor **P**roficiency **2**nd edition
CFI	-	**C**omparative **F**it **I**ndex
DCD	-	**D**evelopmental **C**oordination **D**isorder
FMS	-	**F**undamental **M**otor **S**kills
GFI	-	**G**oodness of **F**it **I**ndex
HRF	-	**H**ealth-**R**elated **F**itness
KTK	-	**K**öperkoordinations**t**est für **K**inder
LMT	-	**L**agrange **M**ultiplier **T**ests
NFI	-	**N**ormed **F**it **I**ndex
MABC	-	**M**ovement **A**ssessment **B**attery for **C**hildren
MAND	-	**M**cCarron **A**ssessment of **N**euromuscular **D**evelopment
MC	-	**M**otor **C**ompetence
PA	-	**P**hysical **A**ctivity
PE	-	**P**hysical **E**ducation
PF	-	**P**hysical **F**itness
RMSEA	-	**R**oot **M**ean **S**quare **E**rror of **A**pproximation
TGMD	-	**T**est of **G**ross **M**otor **D**evelopment
SEM	-	**S**tructural **E**quations **M**odelling
SHR	-	**Sh**uttle **R**un
SiS	-	**S**tay **i**n **S**tep
SLJ	-	**S**tanding **L**ong **J**ump
χ^2	-	Scaled chi-square
yrs	-	**Y**ea**rs**

CHAPTER 1

INTRODUCTION

Introduction

Motor Competence (MC) is often used in the literature as a concept that entails a wide variety of terms (*i.e.*, fundamental motor skill or movement, motor proficiency or performance, motor ability, motor coordination, agility, and fine motor proficiency). MC is used as a global term to describe a person's ability to be proficient on a wide range of motor acts or skills (Fransen, D'Hondt, et al., 2014), which depend of an optimal development of Fundamental Motor Skills (FMS), comprising locomotor, stability and manipulative skills (Gallahue, Ozmun, & Goodway, 2012). Stability skills are natural movements that allow children to feel a body unbalance and quickly readjust through compensating movements (*e.g.*, dynamic and static balance). In all locomotor and manipulative movements, there is a stability element. Locomotor skills are actions that involve vertical or horizontal thrust of the body from one point to another (*e.g.*, leaping, galloping or vertical jump), being the basis for sports and recreational activities. Manipulative skills can de defined as the ability to control different types of objects (*e.g.*, catching, throwing and kicking) and, in their mature form, are essential for playing many sports (Gallahue, Ozmun, & Goodway, 2012).

Childhood is a critical time for the development of MC (Clark, 2007) and in the initial phases of motor development, children's MC involves the mastery of these fundamental motor skills (3 to 7 years old), with the more complex skills (*i.e.*, with more processing of contextual information like manipulative skills) achieving mature forms later that the less complex ones. These FMS are essential for the acquisition of more advanced, specific, and refined movement activities (7 to 14 years old), which are indispensable to engage in various physical activities, sports and games across their lifespan (Gallahue et al., 2012). However, and despite the great importance of these skills, a decline in motor competence has been reported (Vandorpe et al., 2011), with a low mastery prevalence of motor competence in both genders, but specially in girls (Hardy, Barnett, Espinel, & Okely, 2013).

During childhood, motor competence does not develop spontaneously over time, rather is influenced by a combination of environmental factors, opportunities and experiences, encouragement, and instruction (Gallahue et al., 2012). Moreover, a recent meta-analysis concluded that MC interventions delivered by physical education specialists or highly trained classroom teachers can improve MC mastery (Logan, Robinson, Wilson, & Lucas, 2012; Morgan et al., 2013), reinforcing the idea that motor skills need to be taught.

Therefore, structured practice opportunities should be offered to children (Cohen, Morgan, Plotnikoff, Callister, & Lubans, 2014; Hardy, Reinten-Reynolds, Espinel, Zask, & Okely, 2012). Schools and physical education classes are presented as the best place to promote a gradual and positive development of MC (Bailey, 2006), since increasing physical activity (PA) levels per se does not seem to be enough to enhance MC (Fisher et al., 2005). Nowadays, for most children physical education classes represent the only opportunity to engage in a structured practice that specifically aims the development of MC, physical fitness and PA, especially at high-intensity levels (McKenzie, & Lounsbery, 2013).

At the present time, children tend to engage less and less time in physical activity (Andersen et al., 2006; Strong et al., 2005) while spending more time in sedentary activities (Hills, King, & Armstrong, 2007; Lopes, Santos, Pereira, & Lopes, 2012). This contributes to the overall high prevalence of childhood obesity (Low, Chin, & Deurenberg-Yap, 2009), which can jeopardize present and future health and well-being of children and adolescents.

Motor competence was proposed to have a primordial role in developing active and healthy lifestyles in the theoretical model presented by Stodden and colleagues (Stodden et al., 2008). However, limited research was available when the first model was published. Recently, a comprehensive interpretation of the effects of MC on the positive developmental trajectories of health was proposed (Robinson et al., 2015), reinforcing the Stodden et al. theoretical model. According to research evidences, the strengths of the (positive) relationship between MC and Health-Related Fitness (HRF), and of the (negative) relationship between MC and weight status are high, increase with time, and are paramount for determining actual and future trajectories of health (Robinson et al., 2015). In a recent review article, moderate correlations were found between MC and health-related fitness measures (.27 to .68) (Cattuzzo et al., 2015). Additionally, longitudinal studies corroborate this trend (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Hands, 2008). Several studies found inverse correlations between MC and weight status measures (-.20 to -.62), which are stronger during elementary school years (D' Hondt, Deforche, De Bourdeaudhuij, & Lenoir, 2009; D'Hondt et al., 2010; Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012). Moreover, lower results in physical fitness and higher BMI were found in low MC children (Cantell, Crawford, & Tish Doyle-Baker, 2008), and it seems that the caching up phenomenon does not exist, since low MC children do not approach their peers over time. However, both MC proficiency groups present the same increase trend in regards to their physical fitness, therefore they remain stable over time concerning their physical fitness (Fransen, Deprez, et al., 2014; Hands, 2008).

Given the importance of MC promotion in childhood and the existing possibility of developing it with proper experiences in several contexts (*e.g.*, sports training and PE classes), it becomes vital to be able to evaluate systematically children's MC.

Many different MC assessment instruments have been developed and used for this purpose; however, the wide variation of used instruments makes it difficult to better understand the MC behaviour and the respective relation with other important variables (Robinson et al., 2015). Also, the comparison of results across studies and the development of longitudinal research are difficult to establish (Stodden et al., 2008).

Quantitative (product-oriented) and qualitative (process-oriented) methods can be used to assessed MC (Lam, 2011). Some studies (Cools, Martelaer, Samaey, & Andries, 2009; Wiart & Darrah, 2001) looked closely into different assessment instruments, pointing out the weaknesses and strengths of each one of them. However, these studies were limited to standardized protocols and left out many other instruments regularly used in research. Understanding the several instruments used to assess MC and choosing the best one that fits schools context is the starting point of this thesis. Afterwards, this thesis aims to better understand the MC behaviour in children and adolescents and to compare it with health-related fitness variables.

Based on previous research seven empirical questions have guided the present investigation: (1) It is possible to develop a quantitative instrument that evaluates MC using the three theoretical categories (stability, locomotor and manipulative) and that can be used by physical education professionals? (2) Are older children more proficient than younger children? (3) Is there a gender difference in MC (global and by categories)? (4) Are there differences in health-related fitness (HRF) variables between the groups with higher and lower motor competence? (5) Does the strength of the relationship between motor competence and HRF increase with age? (6) Could MC and its categories be significant predictors for the HRF index and can this model explain higher HRF variance? (7) What is the contribution of MC and its components for the explained variance of HRF during growth?

Taking in consideration the previous questions, we aimed to develop a valid (*i.e.*, with good overall fit indexes), brief and easy to administer instrument, representative of MC with its three components. With that instrument we intend to determine some of the previously reported trends. So, we hypothesized that children would increase their motor competence results during growth and boys would outperform girls in all motor variables. Also, children with a higher level of motor competence would present better results than children with a lower level of competence in all health-related fitness measures regardless of age and gender. Moreover, we expected an increase in the strength of the association between motor competence and health-related fitness index during growth, in both genders. Regarding the relation with HRF, we predicted that motor competence categories would be good predictors of HRF and that the manipulative component would display the most important role is the explained variance of HRF.

This thesis comprises six chapters; introduction (chapter 1), followed by four studies (chapters 2 to 5) and general conclusions (chapter 6). To a better understanding of the thesis ideas, it is possible to divide the four studies into two different parts, each one with two separate studies. The first part (chapters 2 and 3) addresses the assessment of motor competence, and the second part (chapter 4 and 5) aims to investigate the behaviour of motor competence in children from age 6 to 14 years, and the relationship with health-related fitness.

More specifically, in Chapter 2 we present a systematic review of the literature concerning the different instruments used to evaluate motor competence in children and adolescents. Chapter 3 proposes a working developmental model of MC, based on three domains (locomotor, stability, and manipulative) of the theoretical construct of MC, which can be used to evaluate MC. Chapter 4 describes the MC behaviour in a large sample of children from 6 to 14 years; investigating also the differences between two groups with differentiated MC (*i.e.*, higher and low MC), according to gender and age, in health related fitness variables. Interrelationships among motor competence and HRF variables were analysed in chapter 5, where MC components were investigated as predictors for HRF index.

The final section of this thesis (Chapter 6) presents a general conclusion, research limitations, implications and suggestions for future studies in this field.

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CHAPTER 2

THE EVALUATION OF MOTOR COMPETENCE IN TYPICALLY DEVELOPING CHILDREN: A SYSTEMATIC REVIEW

Carlos Luz, Gabriela Almeida, Luís Paulo Rodrigues, Rita Cordovil

THE EVALUATION OF MOTOR COMPETENCE IN TYPICALLY DEVELOPING CHILDREN: A SYSTEMATIC REVIEW

Abstract

Background: The development of motor competence (MC) is essential in childhood. In this respect, previous studies have found several positive associations of the MC with physical activity, cardiorespiratory fitness, physical fitness, and perceived physical competence, as well as an inverse association with weight status. The lack of MC during this stage might, therefore, compromise the future adoption of active and healthier lifestyles.

Purpose: This review aimed at listing and examining the different instruments that have been used to evaluate MC in typically developing children, pointing the weakness and strengths from the perspective of Physical Education (PE) teachers.

Methodology: A systematic search of six electronic databases (Science Direct, Web of Knowledge, Pubmed, ERIC, Academic Search and Sport Discus) was conducted including studies from January 1st, 2000 to October 30th, 2013. The guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Statement were followed and several inclusion criteria were used to assess the eligibility of the studies: i) articles in which the evaluation of MC was a central goal; ii) children from 6 to 14 years old; iii) participants with no health problems or neurodevelopmental disorders; iv) assessment of at least two different MC categories of gross motor skills; iv) any type of study design except review papers; v) articles in which the evaluation of MC was a central goal; vi) articles published or accepted for publication in journals with peer review; vii) published in English language.

Findings: Research designs included cross-sectional, longitudinal or experimental/quasi-experimental. Forty-two articles were identified according to the inclusion criteria. A preference for quantitative measures (20 studies) was verified comparatively to a more qualitative approach (5 studies), although eight studies used both measures. Additionally, we have found that 33 studies used standardized protocol tests and eight studies used protocols developed by the authors. In general the protocols exhibited some strong points, however several presented weaknesses that can limit their application in PE classes, such as the excessive amount of time required, the large number of tasks, the ceiling or floor effects, and the fact that not all MC components are simultaneously evaluated.

Conclusions: Different instruments and methodologies have been used to evaluate MC, however we have found a lack of quantitative standardized protocols, with proper reliability and validity that can be used by PE professionals.

Keywords
Child, adolescent, motor competence, review, physical education.

2.1. Introduction

In general, Motor Competence (MC) can be described as a person's ability to be proficient on an large array of fine and/or gross motor acts or skills (Fransen, D'Hondt, et al., 2014). MC is often used in the literature as a concept that entails a wide variety of terms (*i.e.,* fundamental motor skill or movement, motor proficiency or performance, motor ability, motor coordination, agility, and fine motor proficiency). For the purpose of this study, MC is specifically defined as the mastery of human gross movement, which depends of an optimal development of Fundamental Motor Skills (FMS), comprising locomotor (*e.g.*, leaping, galloping or vertical jump), stability (*e.g.*, dynamic and static balance) and manipulative (*e.g.*, catching, throwing and kicking) skills (Gallahue et al., 2012; Luz et al., 2015). These skills are essential for future acquisition of specialised motor skills (more complex movements) employed in many organized and non-organized physical activities for children and adolescents (Clark, & Metcalfe, 2002). For example, the mastery of specific FMS, like kicking and running, allows a child to successfully play soccer and to be more proficient, achieving higher levels of MC.

Motor competence during childhood is influenced by a combination of environmental factors, opportunities and experiences, encouragement, and instruction (Gallahue et al., 2012), making schools and Physical Education (PE) classes a place of choice to its development. Increasing Physical Activity (PA) levels does not seem to be enough to promote a gradual and positive development of MC (Fisher et al., 2005) therefore, structured practice opportunities should be offered to children (Cohen et al., 2014; Hardy et al., 2012). Since children spend much of their days at school, and is assumed that these have the necessary equipment, personnel and facilities (Bauer, 2011), PE classes are the ideal environment for promoting suitable MC experiences (Bailey, 2006).

For most children, PE is the opportunity they have to engage in structured practice that specifically aims the development of MC, physical fitness, and health-enhancing PA, especially at high-intensity levels (McKenzie, & Lounsbery, 2013). In several countries, PE classes are integrated into the school curriculum from the age of three, with great focus on development of MC (Couturier, Chepko, & Holt/Hale, 2014). Recent findings have shown that MC can be improved with proper training given by PE teachers or highly trained classroom teachers (Morgan et al., 2013), although the former are recognizably in a unique position to provide and promote PE programs that enhance MC (Sallis et al., 2012)

Given the importance of MC promotion in childhood and the existing possibility of developing it with proper experiences in several contexts (*e.g.*, sports training and PE classes), it becomes vital to be able to systematically evaluate children's MC. These evaluations allow to identify possible motor delays, and to assess the effects of motor experiences, providing adequate information for future interventions (Hands, 2002). Many different MC assessment instruments have been developed for this purpose; however, their lack of range in terms of assessed competences represents a major challenge for the physical educator. Furthermore, the wide variation of used instruments has hampered the development of longitudinal research and the comparison of results across studies (Stodden et al., 2008).

Motor competence can be assessed through quantitative and qualitative methods (Lam, 2011). Quantitative methods are generally product-oriented, measuring the performance outcome (*e.g.*, speed, distance) with a more user-friendly approach (Lam, 2011). Qualitative methods are process-oriented, providing insight into the form or characteristics of the movement and comparing it with a mature model of performance. These methods tend to focus on critical components of the movement and usually require a more advanced knowledge on the movement components. In addition, qualitative approaches can be used to identify developmental changes and children's different levels of performance (Lopes et al., 2012; Miller, Vine, & Larkin, 2007). The data that are generated from these two methods are also different since quantitative methods produce ratio data and qualitative methods tend to be ordinal (Wright, & Linacre, 1989).

Numerous instruments have been developed to assess MC in typical and atypically developing children. In a recent review, Cools and colleagues (2009) looked closely into seven MC assessment instruments, pointing out the weaknesses and strengths of each one of them. However, this review was limited to preschool ages and standardized protocols. Our present work adds to this topic by expanding the age range and the type of instruments used (including non-standardized). The aim of this study was to conduct a systematic review of all different instruments used to assess MC in typically developing children, and to point out the weakness and strengths in respect to the applicability by PE or by elementary classroom teachers.

2.2. Methods

The guidelines defined in the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) Statement (Moher, Liberati, Tetzlaff, & Altman, 2009) were used to organize this review.

2.2.1. Eligibility Criteria

Two authors (CL and GA) independently assessed the eligibility of the studies according to the following inclusion criteria: i) articles in which the evaluation of MC was a central goal; ii) studies were the participants age was 6 to 14 years-old, attending primary/elementary school (6–10 years) and middle school (10–14 years); iii) studies where the participants had no health problems or neurodevelopmental disorders (*e.g.*, motor disorders, intellectual disability). In some cases, however, research including children with special needs or disabilities was included when the control group included typically developing children; iv) studies where at least two different MC categories of gross motor skills (*i.e.*, stability, locomotor or manipulative, according to original authors) were assessed, either using product (quantitative) or process (qualitative) measures; v) any type of study design (*e.g.*, cross-sectional, longitudinal or experimental/quasi-experimental) with the exception of review papers; vi) articles published or accepted for publication in journals with peer review, that is, conference proceedings and abstracts were excluded; and finally vii) studies published in English. It should be stressed that articles with the aim of testing the psychometric characteristics of different instruments or with screening purposes were not considered in this work.

2.2.2. Information Sources and Search

Two strategies were used for collecting information. Firstly, a systematic search of six electronic databases (Science Direct, Web of Knowledge, Pubmed, ERIC, Academic Search and Sport Discus) was conducted, using combinations of the following keywords: ‘child’, ‘adolescent’, ‘assessment’, ‘motor skill performance’, ‘fundamental motor skill’, ‘motor coordination’, and ‘motor competence’ with the *AND or *OR operator according to the database. Secondly, in order to refine the search and reduce the possibility of information loss, a snowballing literature search was used. This strategy consists in identifying additional references in the bibliography of the previously selected studies. The literature search was confined to studies from January 1st, 2000 to October 30th, 2013, since this time frame allows capturing all instruments that have been used more recently.

2.2.3. Study Selection

After the initial search, different stages were followed for selecting the studies for analysis, namely: i) removing all duplicates; ii) screening and removing articles based on the title and abstract. When doubts emerged, or when there was insufficient information the full text was retrieved for further analysis in order to make a proper judgement; iii) screening and removing articles based on full text articles selected on the previous step; iv) screening and removing articles based on full text articles incorporated from the snowballing search. All decisions, in all stages, were made independently by two of the authors (CL and GA). The results were conferred after each stage and the following stage would only initiate when full consensus was reached. Thereby there was a total agreement in all final articles.

2.2.4. Data Collection Process

In this stage, CL organized all the information concerning the participants' characteristics, type and nature of studies, tests and measures of MC and principals findings, and GA checked the information and adjusted the terminology used.

2.3. Results

2.3.1 Study Selection

In the first stage, 1606 potentially relevant articles were identified using the keywords combinations. After removing duplicates, 1464 articles remained. After screening the titles and abstracts of potential studies (*n=55*) and with the inclusion of the snowballing literature (*n=12*), 67 full text articles were retrieved. A total of 42 articles met the inclusion criteria and were included in the review for further analysis (Figure 1).

2.3.2 Study Characteristics

Europe (*n=23*) and the Oceania (*n=10*) were the continents with more studies included in the systematic review. Studies with 6 to 10 year-olds were the most common (*n=24*); five studies focused on 10 to 14 year-olds, and 13 studies evaluated children with ages between

3 and 14 years. Regarding the study design, eight articles used a longitudinal approach, seven were quasi-experimental, and 27 reported cross-sectional studies. The nature and type of the instruments used for assessing MC in these studies was diverse, however we found six qualitative standardized protocols, 20 quantitative standardized protocols and eight that used both types. Additionally, qualitative and quantitative protocols developed by the authors were used in seven and one study, respectively (see Table 1).

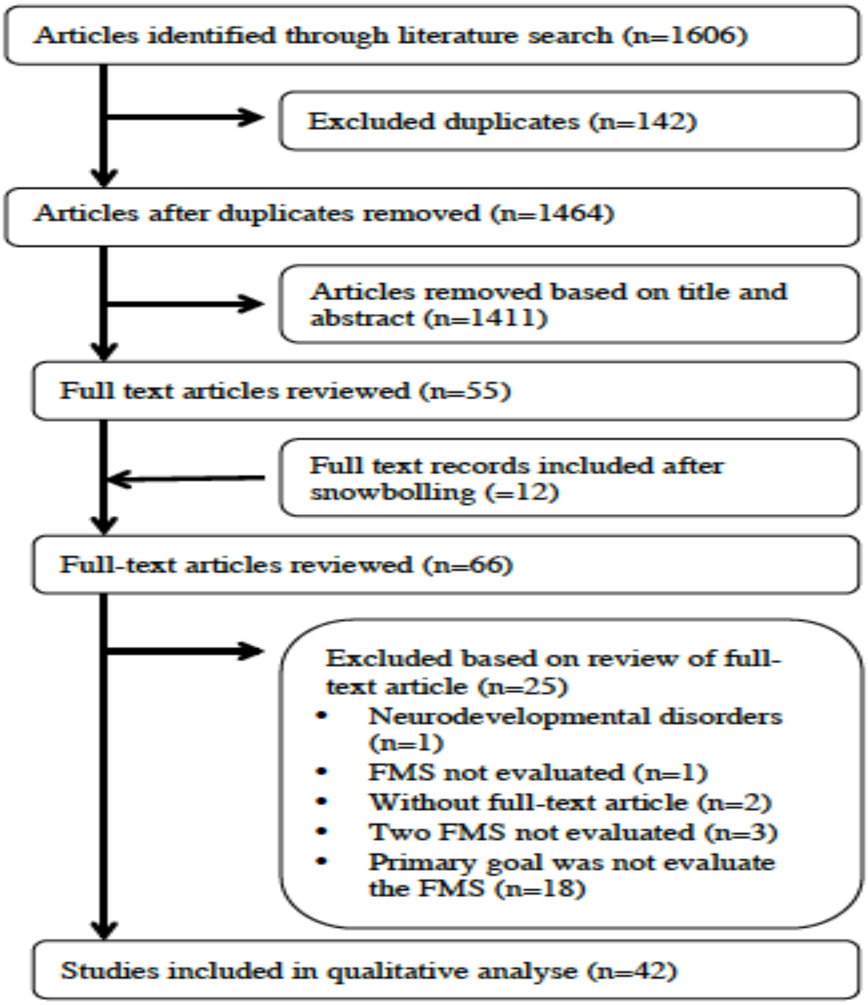

Figure 1 - PRISMA flowchart of studies through the review process

Table 1 - Summary of included studies

References (Authors, year, country)	Objective	Type of study	Test and measures of motor development	Nature	Psychometric characteristics	Comments about the test used
Qualitative standardized protocols						
Akbari et al. (2009) Iran	a) Examine the influence of a program in FMS development; b) Compare the effective traditional games with daily activities on FMS	Quasi-experimental	TGMD-2 (locomotor: run, gallop, hop, leap, horizontal jump, slide; object control: strike, dribble, catch, kick, throw, roll)	Qualitative	NR	NR
Bonifacci et al. (2004) Italy	Examine perceptual, visual-motor abilities and intellectual skills in children with low, average and above average motor abilities	Cross-sectional	TGMD (locomotor: run, hop, jump, slide, gallop, skip, leap; object control: dribble, kick, throw, catch, strike)	Qualitative	NR	NR
Karabourniotis et al. (2002) Greece	Investigate the effect of self-testing activities on the development of FMS in children	Quasi-experimental	TGMD (locomotor: run, hop, jump, slide, gallop, skip, leap; object control: dribble, kick, throw, catch, strike)	Qualitative	NR	TGMD is sensitive in the evaluation of FMS of children 3-10 years
Mitchell et al. (2013) New Zealand	Describe the efficacy of one intervention on improving FMS	Quasi-experimental	TGMD (locomotor: run, hop, jump, slide, gallop, skip, leap; object control: dribble, kick, throw, catch, strike)	Qualitative	NR	NR
Pang and Fong (2013) China	Investigated the fundamental motor skill proficiency of 76 female Hong Kong children ages 6–9	Cross-sectional	TGMD-2 (locomotor: run, gallop, hop, leap, horizontal jump, slide; object control: strike, dribble, catch, kick, throw, roll)	Qualitative	NR	Missing studies reporting normative data from different countries
Spessato et al. (2002)	Compared the fundamental motor status of Brazilian boys and girls	Cross-sectional	TGMD-2 (locomotor: run, gallop, hop, leap, horizontal jump, slide; object control: strike, dribble, catch, kick, throw, roll)	Qualitative		Missing studies reporting normative data from different countries

Table 1 (continued)

Quantitative standardized protocols						
D'Hondt et al. (2010) Belgium	Investigate differences in MC with different BMI levels in children of different ages	Longitudinal	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	NR
D'Hondt et al. (2011) Belgium	Evaluated the short-term effectiveness of a multidisciplinary program in BMI, related measures, and MC	Quasi-experimental	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	Limitation of the KTK to assess manipulative skills and/or fine motor skill performance
D'Hondt et al. (2013) Belgium	Investigate the evolution in MC according to children's BMI and identify predicting factors	Longitudinal	KTK (dynamic balance, hop, jump and stability)	Quantitative	Highly reliable - 0.90 and 0.97. Construct validity: **r=**.60–0.81	NR
Frasen et al. (2012) Belgium	Effect of sampling various sports and of spending many or few hours in sports on fitness and MC	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	NR	NR
Graf (2004) Germany	Examine the association between BMI, motor abilities and leisure habit	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	NR	NR
Hebestreit et al. (2008) Germany	Assess the difference between head circumference and MC in born prematurely and typical children	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	NR
Hands (2008) Australia	Report the results of a subsample of children participating in a longitudinal study tracking fitness and skill levels of children	Longitudinal (5 years)	MC screening test (SiS): balance, hop; run; catch. Other measures: throw; horizontal jump	Quantitative	Test-retest reliability for each item ranging between .87 to.90. The validity was reported by the original authors	NR

Table 1 (continued)						
Lopes et al. (2011) Portugal	Relationships among MC, physical fitness and PA in children from 6 to 10 years	Longitudinal (5 years)	KTK (dynamic balance, hop, jump and stability)	Quantitative	NR	NR
Lopes et al. (2012) Portugal	Examine the influence of MC, physical fitness and PA on the development of subcutaneous adiposity in children	Longitudinal (5 years)	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	
Lopes et al. (2012) Portugal	Analyze the association between MC and BMI	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	A more comprehensive MC assessment may provide a clearer picture
Lopes et al. (2013) Portugal	Evaluate the relationship between MC and academic achievement in children aged 9–12 years	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	NR
Martins et al. (2010) Portugal	Investigate the association between PA, 1-mile run/walk, MC and BMI	Longitudinal (5 years)	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	NR
Nourbakhsh (2006) Iran	Study the perceptual-motor abilities of fifth grade elementary school female pupils	Cross-sectional	BOTMP (Fine Manual Control, Manual Coordination, Body Coordination, Strength & Agility)	Quantitative	Reliability = .99 Validity = .88	NR
Ratzon et al. (2000) Israel	Examine the effects of diabetes during pregnancy on the long-term MC and to study correlations between glycemic control and MC	Cross-sectional	BOTMP (Fine Manual Control, Manual Coordination, Body Coordination, Strength & Agility)	Quantitative	NR	NR

Table 1 (continued)

Vandendriessche et al. (2011) Belgium	Examine variance in MC by morphological and fitness characteristics	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	NR	NR
Vandendriessche et al. (2012) Belgium	Examined the relationship between SES, sport participation, morphology, fitness and MC	Cross-sectional	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by other authors	NR
Vandorpe et al. (2011) Belgium	a) Produce current gender- and age-specific reference values for MC of Flemish children b) Compare the raw scores and MQ values with the norms of the original sample	Longitudinal	KTK (dynamic balance, hop, jump and stability)	Quantitative	NR	NR
Vandorpe et al. (2012) Belgium	Examine the relationship between MC and organized sports participation over time	Longitudinal	KTK (dynamic balance, hop, jump and stability)	Quantitative	The reliability and validity were reported by the original authors	NR
Wrotniak et al. (2006) United States	Examine the relationship between motor proficiency and PA in 8- to 10-year-old children	Cross-sectional	BOTMP short form (Fine Manual Control, Manual Coordination, Body Coordination, Strength & Agility)	Quantitative	The reliability and validity were reported by the original authors	Detecting specific aspects of motor skill difficulties and determining where improvement needs to occur is difficult
Wrotnick et al. (2009) United States	Examine the relations of motor abilities among siblings using a comprehensive measure of motor proficiency	Cross-sectional	BOTMP short form (Fine Manual Control, Manual Coordination, Body Coordination, Strength & Agility)	Quantitative	Reliability coefficient range from .84 to .87	Comprehensive measure of MC. Limitations: overall measures of MC were the sum of 14 items; does not provide specific information on procedural skills

Table 1 (continued)

Quantitative and qualitative standardized protocols

Ekornås et al. (2010) Norway	Compare MC and self-perceived competence between children with and without anxiety disorders	Cross-sectional	MABC	Quantitative and qualitative	NR	NR
Gabbard et al. (2012) United States	Examine the association between children's ability to mentally represent action and general MC	Cross-sectional	MABC -2 - manual dexterity, aiming and catching, and balance.	Quantitative and qualitative	The reliability and validity were reported by other authors	NR
Haga (2008) Norway	Test physical fitness in children with movement difficulties and a comparison group without movement difficulties	Cross-sectional	MABC PF: jumping; throwing; climbing; running	Quantitative and qualitative	The MABC has a inter-rater reliability of .70. PF - The construct validity - .93 (girls); .89 (boys).	PF test - activities that are naturally included in everyday play activities. The test situation is characterised by a game-style atmosphere that may facilitate children's motivation to participate and perform
Hands et al. (2009) Australia	Examine the interrelationships among PA, physical fitness and MC and compare with high and low levels participants.	Cross-sectional	McCarron Assessment of Neuromuscular Development (fine motor and gross motor tasks - Finger–Nose–Finger, Jumping for Distance, Heel–Toe–Walk, and Standing on One Foot)	Quantitative and qualitative	The reliability and validity were reported by the original authors	NR

Table 1 (continued)

Livesey et al. (2011) Australia	Examined the link between motor performance and peer relations	Cross-sectional	MABC-2 - manual dexterity, aiming and catching, and balance.	Quantitative and qualitative	NR	Does not distinguish well the highest of the typical performances
Rigoli et al. (2012) Australia	Examine whether the association between MC and emotional functioning is mediated by self-perceptions	Cross-sectional	MABC - manual dexterity, aiming and catching, and balance.	Quantitative and qualitative	Reliability coefficient of 0.80 for total test score and coefficients ranging from .73 to .84 for the individual component scores.	NR
Schurink et al. (2012) Netherlands	Examine whether the association between MC and emotional functioning is mediated by self-perceptions	Cross-sectional	MABC - manual dexterity, aiming and catching, and balance.	Quantitative and qualitative	The reliability and validity were reported by other authors	More variety in motor skill performance is needed
Zhu et al. (2011) Taiwan	Investigate the associations between obesity and MC in children with and without DCD	Cross-sectional	MABC - manual dexterity, aiming and catching, and balance.	Quantitative and qualitative	The reliability and validity were reported by the original authors	NR
Non standardized qualitative protocols						
Beurden et al. (2002) Australia	Describe the proportion of children from 18 schools who achieved MC mastery.	Cross-sectional	Stability: static balance, vertical jump; locomotor: sprint run, side gallop, hop; object control: kick, catch, overhand throw	Qualitative	The reliability and validity were reported by the original authors	NR
Boyle-Holmes et al. (2010) United States	Describes a comparative evaluation of Michigan's Exemplary Physical Education Curriculum in elementary schools	Quasi-experimental	Locomotor (leap), posture (lift and carry), and manipulative skills (forehand strike)	Qualitative	No psychometric properties	Vigilance and attention to detail over the entire test; fatigue may have affected scoring

Table 1 (continued)

Foweather et al. (2008) England	Examine the efficacy of an after-school multiskill club designed to increase FMS proficiency	Quasi-experimental	Stability: vertical jump, static balance; locomotor: sprint run, leap; Object control: kick, catch, throw	Qualitative	The reliability and validity were reported by the original authors	NR
Hume et al. (2008) Australia	Describe the relationship (a) among MC, PA, and BMI, and (b) among MC, PA and gender	Cross-sectional	Locomotor: run, vertical jump, dodge; Object control: overhand throw, two-handed strike, kick	Qualitative	NR	Strength: inclusion of five FMS commonly used in children's games, sports, and physical activities
Okely et al. (2001) Australia	Examine the relationship between cardiorespiratory endurance and FMS proficiency	Cross-sectional	Six-item Fundamental Movement Skills Battery (Locomotor (run and jump) and object-control (catch, throw, kick, and strike) skills)	Qualitative	The reliability and validity were reported by the original authors	NR
Okely et al. (2004) Australia	Examine associations of FMS with measures of body composition among children and adolescents	Cross-sectional	Six-item Fundamental Movement Skills Battery (Locomotor (run and jump) and object-control (catch, throw, kick, and strike) skills)	Qualitative	Other authors have established the reliability (.75) and validity (content validity was assessed by a panel of 52 FMS experts)	Process-oriented assessments of FMS were used, because they more accurately identify specific topographical aspects of the movement
Okely and Booth (2004) Australia	Examine the prevalence and socio- demographic distribution of skill mastery and near-mastery for boys and girls in Years 1 through 3	Cross-sectional	Six-item FMS - hop, skip, side gallop, over arm throw, kick (stationary ball), leap, two- hand strike, dodge, sprint run, catch, static balance and vertical jump.	Qualitative	The reliability and validity were reported by the original authors	Instrument are more accurately in identify specific aspects of the movement

Table 1 (continued)						
Non standardized quantitative protocols						
Kalaja et al. (2011) Finland	Investigate whether students' MC and self-reported PA increase through specific intervention	Quasi-experimental	Stability: flamingo standing test, rolling test, rope jumping test; locomotor: shuttle run test, leaping test; object control: accuracy throwing test, figure-8 dribbling test	Quantitative	The reliability was reported by other authors and showed moderate to good reliabilities (.46 - .95)	Not all of the tests have been proven as reliable in previous studies

BMI – Body Mass Index; BOTMP - Bruininks-Oseretsky Test of Motor Proficiency; DCD – Developmental Coordination Disorder; FMS – Fundamental Motor Skills; KTK - Körperkoordinationstest für Kinder; Movement Assessment Battery for Children – MABC; MC – Motor Competence; NR – Not Reported; PA – Physical Activity; PE – Physical Education; PF - Physical Fitness; SiS – Step in Step; TGMD - Test of Gross Motor Development

2.3.3 Measurement of MC

As mentioned earlier, the nature of the measure used to evaluate MC proficiency, as well as the tests or protocols used, differed among the studies.

Qualitative standardized protocols

With regard to qualitative instruments, the Test of Gross Motor Development (TGMD - 1st or 2nd edition) (Ulrich, 1985, 2000) was the only standardized protocol found in the literature, having been used in 6 studies (Akbari, Abdoli, & Shafizadeh, 2009; Bonifacci, 2004; Karabourniotis, 2002; Mitchell et al., 2013; Pang, & Fong, 2009; Spessato, Gabbard, Valentini, & Rudisill, 2012). The main goal of the TGMD is to identify children, in the age range from 3 to 10 years, which are significantly behind their peers in gross motor performance. This battery includes locomotor and manipulative skills and takes about 15 to 20 minutes per participant. Comparing the two editions of this protocol, it was found that the revised edition has several improvements concerning reliability (minimum of .85) and validity aspects. In addition, a new manipulative skill (underhand roll) was added and a locomotor skill (skip) was excluded. Age norms for both subtests are presented divided into half-year increments. The discrimination of skill level (below or above), the good reliability and validity presented, and the assessment of manipulative skills are the strong points of this battery. However, since stability skills are not evaluated, the results tend to have ceiling or floor effects. Furthermore, the existence of cultural biases in some skills are also considered weaknesses of this test battery (Cools et al., 2009). Moreover, for PE professionals it is too time consuming to assess all twelve tasks of the TGMD in a PE class.

Quantitative standardized protocols

The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) or its short form was used in four studies (Nourbakhsh, 2006; Ratzon, Greenbaum, Dulitzky, & Ornoy, 2000; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006; Wrotniak, Salvy, Lazarus, & Epstein, 2009). The BOTMP and the BOT-2 (Bruininks, & Bruininks, 2005) evaluate fine and gross movement skill development in children and adolescents and are used for screening, evaluation, research, and program planning. In addition, they support diagnoses of motor impairments in individuals with ages between 4 to 14.5 years for the BOTMP, and 4 to 21 years for the BOT-2 (Bruininks, & Bruininks, 2005; Deitz, Kartin, & Kopp, 2007). Both instruments exhibit good validity and reliability, and both assess four major components: fine manual control, manual coordination, body coordination, and strength and agility. BOTMP and BOT-2 have 46 and 58 items, respectively. A short form of BOT-2, consisting of 14 items, was developed for a fast screening of overall motor proficiency. This short form presents a high correlation (.80) with BOT-2 and takes about 15 to 20 minutes to apply. The evaluation with the entire BOT-2 takes 45 to 60 minutes. The strengths pointed by the authors include: the possibility of using the short form for screening for possible motor coordination problems, the existence of separated gross and fine motor composite scores that allow comparisons, and the fact that this instrument covers a wide age range. However, there are also some weaknesses. As examples, age equivalent scores are based on extrapolations, scoring can be time-consuming, and several sessions with the same participant may be required due to participant's fatigue (for more information see Cools et al., 2009 and Deitz, 2007). Another important disadvantage is that the goal of the instrument is to identify possible motor coordination problems and not to assess MC specifically, so it is mostly used for clinical assessment and not as an ideal instrument for PE professionals.

The Stay in Step (SiS) (Larkin, & Revie, 1994) was solely used in one study (Hands, 2008) and it is a validated gross motor screening test to identify children with poor motor development. This test has a good test-retest reliability for each item, ranging between r= .87 to r= .90, and can only be used with 5 to 7 year-olds. The SiS consists in the evaluation of four motor skills including stability, manipulative, locomotor and velocity. The narrow age range makes this a limited instrument to apply in the school context.

The Körperkoordinationstest für Kinder (KTK) (Kiphard, & Schilling, 1974) was the most used protocol to assess MC, with 15 studies. This test uses a quantitative method that refers to a norm and assesses gross body control through locomotor and stability outcomes. It can be used with typically developed children as well as with children with brain damage, behavioral problems or learning difficulties (Cools et al., 2009; Lopes et al., 2012). The KTK protocol presents four motor tests with construct and content validity (Kiphard, & Schilling, 2007). Additionally, it presents good intra-rater reliability (≥.80) and test-retest reliability (>.85), and it can be used in children with ages between 5 and 14 years (Cools et al., 2009). Few and easy motor tasks, with a good reliability, and a fast assessment procedure, are considered major strengths of this protocol. However, some weaknesses can be mentioned, as the fact that this instrument only uses four motor tests to assess MC, it does not evaluate manipulative skills, and it uses old normative data. In fact, the absence of a manipulative component assessment represents a large fragility, since these skills are believed to be the best indicators to explain the association between MC and cardiovascular fitness, across childhood and into adolescence (Barnett, Morgan, Van Beurden, Ball, & Lubans, 2011; Stodden, Gao, Goodway, & Langendorfer, 2014).

Quantitative and qualitative standardized protocols

Eight studies used a mixed quantitative and qualitative approach. The McCarron Assessment of Neuromuscular Development (MAND) (McCarron, 1997) was used in one study (Hands, Larkin, Parker, Straker, & Perry, 2009), and the Movement Assessment Battery for Children (MABC) 1st edition (Henderson, & Sugden, 1992) or 2nd edition (Henderson, Sugden, & Barnett, 2007) was employed in five (Ekornås, Lundervold, Tjus, & Heimann, 2010; Haga, 2008; Livesey, Lum Mow, Toshack, & Zheng, 2011; Schurink, Hartman, Scherder, Houwen, & Visscher, 2012; Zhu, Wu, & Cairney, 2011) and two studies (Gabbard, Caçola, & Bobbio, 2012; Rigoli, Piek, & Kane, 2012), respectively.

The McCarron Assessment of Neuromuscular Development (McCarron, 1997) was developed as a tool for health professionals, to screen and evaluate 3.5 to 18 year-old children. The MAND is an individually administered, norm-referenced assessment tool comprising quantitative and qualitative measures of five fine motor and five gross motor skills. Raw scores for each item are converted to scaled scores based on the participant's age. A measure of overall motor skills (Neuromuscular Developmental Index) is given through the sum of the ten-scaled scores. The MAND presents a good reliability ranging between .67 and .98 (McCarron, 1997), and has showed good concurrent validity (Tan, Parker, & Larkin, 2001). It has many advantages, for example, it has a large age range of application and it includes both qualitative and quantitative components. However, the absence of manipulative skills, an important MC component, and the lack of similarity between most of the tests and the activities or sports that children are familiar with, can be seen as disadvantages. The Movement Assessment Battery for Children (M-ABC) 1st edition (Henderson, & Sugden, 1992) permits to identify delays in the development of MC in 4 to 12 year-old children, divided by four age bands. This test is composed by eight motor tasks per age band that evaluate three movement categories: fine motor skills (manual dexterity), manipulative skills (aiming and catching), and stability (static and dynamic). The skills are evaluated in a 6-point rating Likert scale, where 5 is the weakest and 0 the best performance. The M-ABC 2st edition (Henderson et al., 2007) presents the same objective with also eight motor tasks (same categories), however this edition allows the assessment of 3 to 16 year-old children divided by three age bands.

The total test score is given by the sum of the eight item standard scores (range 8–152). Both editions show good validity and sufficient reliability (Chow, & Henderson, 2003; Henderson, & Sugden, 1992; Henderson et al., 2007; Tan et al., 2001) and take about 20 to 30 minutes per participant. One of the major advantages is the simple test administration that allows the collection of a large sample in a short period of time. On the other hand, the ratio between the number of tasks and the time required is inadequate (for further information see Cools et al., 2009), and the lack of assessment of locomotor skills is a very important disadvantage, which makes this instrument inadequate to assess MC for PE professionals.

Non-standardized qualitative protocols

Qualitative protocols specifically developed for the study using a process-based approach with stability, locomotor and manipulative skills were used in seven studies (Beurden et al., 2002; Boyle-Holmes et al., 2010; Foweather et al., 2008; Hume et al., 2008; Okely, Booth, & Chey, 2004; Okely, Patterson, & Booth, 2001; Okely, & Booth, 2004). These protocols have similarities, in the sense that all decomposed each movement skill in various components and scored each of the components as present or absent in four or five trials. For all the mentioned studies, the components of each movement skill protocol were established based on the Get Skilled: Get Active program and FMS assessment (NSW Department of Education and Training, 2000). Three of the studies (Hume et al., 2008; Okely et al., 2004, 2001) did not evaluate any stability skills, two used solely one stability task, and only two studies used two tasks (static balance, vertical jump). The tasks used for the assessment of locomotor (*e.g.,* sprint run, hop, side gallop, skip and dodge) and manipulative skills (kick, catch, overhand throw and forehand strike) were identical in all 7 studies; however, the number of tasks used differed among the studies. All locomotor and manipulative tasks used in these studies, with the exception of run and leap, presented a good reliability (≥.70). In addition, the content validity was established by 52 experts (Department of Education, 1996). The use of several locomotor and manipulative skills that are similar to activities or sports that students are familiar with (Okely et al., 2004), is considered the greatest advantage of these protocols. However, the time-consuming data collection, the need of expert evaluators, the lack of age referenced standardization, and the undervaluation of the stability skills represent important weaknesses for the use of these protocols in a school context.

Non-standardized quantitative protocols

Only one study used a specifically developed quantitative protocol (Kalaja, Jaakkola, Liukkonen, & Digelidis, 2012). Here, several tasks were used to assess all components of MC. These tasks showed moderate to high reliabilities. The use of at least two tasks to evaluate each MC component and the short time required for data collection are two of the strengths of this protocol. The lack of tasks related to some MC components (*e.g*., catch), and the lack of similarity between some of the tasks (*e.g*., the rolling test) and familiar sport activities, can be considered as limitations of this protocol.

2.4. Discussion

The main goal of this systematic review was to collect and synthesize existing protocols developed to evaluate MC in typically developing children, which can be used by PE professionals. Of the 42 eligible studies, 13 used qualitative protocols, 21 preferred a quantitative approach and 8 studies used protocols including both qualitative and quantitative procedures, so a preference of quantitative (product-oriented) methodologies over qualitative (process-oriented) methodologies was found. It is interesting to note that, comparative to other continents, the use of quantitative methods are preferred in Europe. Both methodologies have advantages and disadvantages. The quantitative instruments found in the review process have several weaknesses concerning their implementation by PE professionals, namely: i) there is a limited range of motor tasks; ii) they do not evaluate all MC components; ii) they screen motor coordination problems instead of MC; iii) limited age range; iv) lack of similarity between some of the tasks and principal sport activities.

Qualitative methods allow to distinguish more accurately between different stages of specific skill performance and, therefore, provide sensitive information that grants the teacher with the knowledge of the specific components of a skill a student should practice (Hands, 2002). This allows for a better organization of PE classes. However, the qualitative tests also have some important disadvantages concerning their use by PE professionals. Some examples are the needed expertise and training of the evaluator, the time necessary to assess each participant, usually in the form of video recording observation, and the obligation of parental consent for video footage. Although a trained PE teacher is expected to be able to administer the assessment without the need of video recording, in many countries primary school teachers are responsible for PE administration and they do not have the necessary knowledge or expertise to assess movement skills

(Morgan, & Hansen, 2013; Xiang, Lowy, & Mcbride, 2002). Another disadvantage is the fact that an ideal performance pattern may not exist. Traditionally, the mastering of specific motor tasks (expertise) has been described as the capacity to consistently replicate a specific movement pattern, increasing the automaticity of movement (Seifert et al., 2012) and eliminating movement patterns that are considered detrimental for the correct movement. However, it is known that even elite athletes are unable to reproduce invariant movement patterns, despite years of practice (Bauer, & Schöllhorn, 1997), showing that the exact repetition of the same movement is impossible to achieve.

For the reasons stated above, knowing that qualitative and quantitative measures are correlated (low to moderate) (Logan, Robinson, Rudisill, Wadsworth, & Morera, 2012; Miller et al., 2007; Roberton, & Konczak, 2001; Valentini et al., 2015), and that quantitative methods generally ensure a high level of reliability over time and between evaluators (Spray, 1987), it is natural that quantitative tests would be a good option for assessment in PE classes or in other sport contexts.

Our results also show that 34 studies used standardized protocol tests (KTK was the most used), while in eight studies the authors developed the protocols. The use of standardized protocols has several advantages, such as the guarantee of previously tested reliability and validity (Portney, 2009). The lack of statistically robust psychometric properties (reliability, validity) and the impossibility of comparing the results to normative data are pointed as the major weaknesses of using specifically developed protocols. Despite the potentialities of using standardized tests, it is important to mention some disadvantages that might limit the use of the protocols we have found, from the point of view an of school implementation: i) the acquisition cost of standardized protocols tests; ii) the need to evaluate the three components of MC, which are not included in all standardized protocols tests; iii) time constraints, since standardized protocols usually have several tests and might be time consuming.

The greatest strength of our study is the correct application of the different steps suggested by the PRISMA statement and the determination of the risk of bias for the eligible studies. However, some limitations can be mentioned such as the date range for the eligible studies, and the fact that only English language studies were used.

The studies analysed in this review used different instruments for assessing MC. All the found protocols exhibited particular weaknesses and strengths, and were targeted to specific goals and populations. Considering that a practical and easy to administer instrument that encompasses the full MC spectrum does not seem to exist, the need for a standardized protocol test using the three MC components is warranted for both PE and research settings.

2.5. Conclusions

In this study, a systematic review of the presented methodologies to evaluate MC in typically healthy children was conducted. MC has been assessed through qualitative or quantitative methodological approaches using several standardized protocol tests, or protocols have been developed according to the objectives of the evaluation. Given the existence of positive associations between MC and health benefits (Lubans, Morgan, Cliff, Barnett, & Okely, 2010) and the important role that PE plays in the development of MC (Morgan et al., 2013), it would be of great interest to create a standardized protocol test to evaluate MC in its full spectrum. Such instrument does not seem to exist but we believe that it would be of paramount importance for both PE and research related settings.

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2.6. References

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CHAPTER 3

DEVELOPMENT AND VALIDATION OF A MODEL OF MOTOR COMPETENCE IN CHILDREN AND ADOLESCENT

Luz, C., Rodrigues, L. P., Almeida, G., & Cordovil, R. *(2015). Development and validation of a model of motor competence in children and adolescents*. Journal of Science and Medicine in Sport 01/2016; DOI:10.1016/j.jsams.2015.07.005.

Development and Validation of A Model of Motor Competence in Children and Adolescent

Abstract

Objectives: This study was aimed at developing a quantitative model to evaluate motor competence (MC) in children and adolescents, to be applicable in research, education, and clinical contexts.

Design: Cross-sectional.

Methods: A total of 584 children (boys n= 300) with ages between 6 and 14 years were assessed using nine well known quantitative motor tasks, divided into three major components (stability, locomotor and manipulative). Structural equation modelling through EQS 6.1 was used to find the best model for representing the structural and measurement validity of MC.

Results: The final MC model was composed by three latent factors closely related with each other. Each factor was best represented by two of the initial three motor tasks chosen. The model was shown to give a very good overall fit (χ^2=12.04, p=.061; NFI=.982; CFI=.991; RMSEA=.059).

Conclusions: MC can be parsimoniously represented by six quantitative motor tasks, grouped into three interrelated factors. The developed model was shown to be robust when applied to different samples, demonstrating a good structural and measurement reliability. The use of a quantitative protocol with few, simple to administer and well known, motor tasks, is an important advantage of this model, since it can be used in several contexts with different objectives. We find it especially beneficial for physical educations teachers who have to regularly assess their students.

Keywords

Motor competence; physical education; quantitative instruments; locomotor; manipulative; stability.

3.1. Introduction

In the last two decades a growing body of evidence suggests that early Motor Competence (MC) is of paramount importance for developing an active and healthy lifestyle (D. F. Stodden et al., 2008). MC is used as a global term to describe a person's ability to be proficient on a wide range of motor acts or skills (Fransen, D'Hondt, et al., 2014). This ability has been described in the literature also as motor coordination, motor performance, or motor proficiency. In the initial phases of motor development, children's MC involves the mastery of fundamental motor skills that are the foundations for the mastery of specialized motor skills. It has been reported that physical activity (Holfelder & Schott, 2014; Lopes, Rodrigues, Maia, & Malina, 2011), cardiorespiratory fitness (Haga, 2009; Vandendriessche et al., 2011), physical fitness (Hands et al., 2009a), and perceived physical competence (Barnett, Morgan, Beurden, & Beard, 2008; Barnett et al., 2011), have positive effects and associations with MC, as well as an inverse association with weight status (Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012) in children and adolescents. This has provided emerging evidence to the theoretical model proposed by Stodden and colleagues (2008).

MC as a theoretical construct is considered to be subdivided into locomotor (*e.g.*, leaping, galloping or vertical jump), stability (*e.g.*, dynamic and static balance) and manipulative (*e.g.*, catching, throwing and kicking) (Gallahue et al., 2012) proficiency. However, this structure is not always reflected in research and/or clinical settings where MC constitutes the subject of interest. Several standardized tests (*e.g.,* TGMD, KTK), and a number of different non-standardized protocols (Hume et al., 2008; Okely & Booth, 2004), found in the literature, are deemed to evaluate MC but do not follow the theoretical MC construct. For example, the TGMD does not evaluate stability and the KTK does not evaluate manipulative proficiency. Furthermore, most instruments and protocols are restricted to a specific age, or narrow age-range, either due to the developmental restricted age window of the motor tasks, or to the nature of the used scoring procedures (quantitative or qualitative).

This great discrepancy between the accepted theoretical construct of MC and its application in research and/or clinical settings shows the lack of a robust conceptual and working model of MC that could be successfully used in different settings and developmental ages. To our knowledge, no studies have been presented that validate the theoretical MC model structure using the original three categories. Some studies have used structural equation modelling or confirmatory factor analysis techniques to look for the structural validity of instruments *(e.g.,* M-ABC (Schulz, Henderson, Sugden, & Barnett, 2011), TGMD (Kim, Kim, Valentini, & Clark, 2014) but the instruments themselves were not in full agreement with the theoretical MC model.

The main objective of this study was to establish a working developmental model of MC, based on three domains (locomotor, stability, and manipulative) of the theoretical construct of MC. We hypothesized that each of these three categories is represented by age independent significant motor tasks that can be objectively measured (product).

To achieve this purpose we have assessed children using several motor tasks representative of each MC category in the literature, and worked with the data to find a representative and parsimonious model of MC using specific Structural Equations Modelling (SEM) techniques.

3. 2. Methods

Participants

A total of 584 children (300 males), aged 6 to 14 years (*M*=10.60, *SD*=2.40), participated in this study. Children were randomly selected from public Portuguese schools and had no known learning disabilities or pre-existing motor limitations. A local ethics committee approval was obtained and parents provided written informed consent. Two Physical Education (PE) teachers with 10 years of experience were trained to collect the data in regular scheduled classes (each teacher always assessed the same group of tasks).

Measures and Procedures

Motor Competence

Three tests for each MC category (stability, locomotor, and manipulative (Gallahue et al., 2012) were selected from the most used protocols and instruments in the motor development literature. Inclusion criteria were being quantitative (product-oriented) motor tests without a marked developmental (age) ceiling effect, and of feasible execution.

Stability tests were*:* a) Balance beams (Kiphard & Schilling, 2007)–walking backwards on three balance beams with 3m in length but of decreasing widths (6, 4.5 and 3cm). Each participant had three attempts per beam and each attempt had the maximum score of 8 points. The total score was given by the sum of points in the three balance beams (72 total possible points); b) Shifting platforms (Kiphard & Schilling, 2007)–moving sideways for 20s using two wooden platforms (25cm x 25cm x 2cm). Each successful transfer from one platform to the other was scored with two points (one point for each step). Participants were given two trials and only the best score was considered; c) Jumping laterally (Kiphard & Schilling, 2007)–jumping sideways with two feet together over a wooden beam as fast as possible for 15s. Each correct jump scored 1 point and the best result over two trials was considered. Locomotor tests were*:* a) Hopping on one leg over an obstacle (Kiphard & Schilling, 2007)–jumping over a stack of foam blocks 5cm high with one foot, reaching the floor with the same foot. After a successful attempt with each foot, the height was increased by adding one foam block. Participants received three, two or one point(s) for each successful performance on the first, second or third trial, respectively. Therefore, each child had three attempts at each height and on each foot. The testing was stopped when a height trial was not successfully completed with both feet. The total score was given by the sum of points at all the heights; b) Shuttle Run (SHR) (Vicente-Rodríguez et al., 2011)-running at maximal speed to a line placed 10 meters apart, picking up a block of wood, running back and placing it on or beyond the starting line. Then running back to retrieve the second block and carry it back across the finish line. The final score was the best time of the two trials; c) Standing Long Jump (SLJ) (Ara, Moreno, Leiva, Gutin, & Casajús, 2007)–jumping with both feet simultaneously as far as possible. The final score (the better of 2 attempts) was the distance (in m) between the starting line and the back of the heel at landing closest to the line. Manipulative tests were*:* a) Wall toss test (Beashel, 2004)–throwing a tennis ball with an overarm action against the wall (2m distance), attempting to catch it with both hands over 30s. The final score was given by the better result (number of catches) in 2 attempts; b) Throwing Velocity (Stodden et al., 2014)-throwing a baseball (circumference: 22.86cm; weight:142g) at a maximum speed against a wall using an overarm action. Three trials were performed, and the final score was given by the best result; and c) Kicking Velocity (Stodden et al., 2014)–kicking a soccer ball n.º4 (circumference: 64cm, weight: 350g) at a maximum speed against a wall using a kicking action. Three trials were performed, and the final score was given by the best result. Ball peak velocity was measured with a Pro II Stalker Radar Gun in both tests.

Procedures

Participants completed a general warm-up before the beginning of the tests. Then, groups of five students were evaluated in the same task order. Participants observed a demonstration of the proficient technique and had the opportunity to experiment with each task one time before their performance. Motivational feedback was given; however no verbal feedback on skill performance was provided. In the throwing/kicking tasks, children were instructed to throw/kick the ball as fast as they could.

Data analyses

In order to assess the plausibility and validity of our theoretically driven MC model, we used a special multi-group confirmatory factor analysis, known as stack model (Byrne, 2006). In the first two steps of this procedure, the full sample (584 subjects) was randomly split in half maintaining the gender proportionality. The first half (292 subjects) was used as a calibration sample (to set the initial best model to entail MC according to the theoretical framework), and the second as a validation sample, used to assure that the previous chosen model (factors and loading items) was able to reproduce every other data.

On the third phase (cross validity) we formally tested for measure and structural invariance between the two split halves. To test for measure invariance, the formal structure from the calibration sample was imposed on the validation sample while all parameters were left free. Using a more restricted approach (tight cross validation), structural invariance was also imposed to the validation sample, with all parameters constrained to the calibration model values.

The absolute fit of the models (individual and multi-group analysis) was evaluated using the Satorra and Bentler scaled chi-square (χ^2) (1994) with correction for non-normality, while the relative fit was assessed using the comparative fit index (CFI), the normed fit index (NFI), and the goodness of fit index (GFI). For these indices, values over .95 and up to 1.0 are deemed indicative of a good fit.

The root mean square error of approximation (RMSEA) and respective confidence intervals (CI) were used for evaluating how well the model-implied reproduced the variance-covariance matrix of the data, keeping in mind that RMSEA values as low as .06 represent a good fit to the model (Bentler, 2006; Byrne, 2006; Raykov & Marcoulides, 2006). EQS Lagrange Multiplier Tests (LMT) for adding and deleting parameters were interpreted within the theoretical framework for each model tested in the calibration phase, and alterations made accordingly. Variables were considered for deletion when LMT suggested that such procedure resulted in a significant improvement of the model fit. Each consecutive model was compared with the previous using the chi-square and degrees of freedom change, and was only retained when this comparison showed statistical significance. All analyses were conducted using the EQS 6.1 computer program (Multivariate Software, Inc.).

3. 3. Results

In the calibration phase (phase 1) the initial formulation of the MC model was set according to the theoretical formulation with three factors (stability, locomotor, and manipulative), and three possible items (motor skill tasks) accounting (loading) on each factor. Departing from this theoretical model, we examined the solution according to the significance of the loading coefficients, R^2 values of the variables equations, and indices of overall and relative fit (χ^2, CFI, NFI and RMSEA). EQS Lagrange Multiplier tests for adding and deleting parameters were used to improve the model fit, according to theoretical interpretation. As a result of this procedure, three variables (hopping on one leg over an obstacle, walking on a balance beam, and tossing and catching a ball) were consecutively dropped from the original model, resulting in a final model of MC with six motor tasks (jumping laterally, shifting platforms, SHR, SLJ, throwing velocity, kicking velocity) and three correlated factors showing a very good overall fit (χ^2=12.04, p=.061; NFI=.982; CFI=.991; RMSEA=.059; CI(RMSEA)=(000 - .106). This final standardized solution is shown in Figure 2, and the fit indexes values for the four consecutive models tested can be seen in Table 2.

In the second step (validation phase), data from the second half of the sample was tested using the final specified model from the calibration sample. Overall indices showed a very good adjustment of this model to the data (see Table 2), similar to the one found in the validation sample. In the third step (cross validation phase), in order to test for the cross validity of the model we formally tested for measure and structural invariance between the two split halves. To test for measure invariance, the formal structure from the calibration model 4 sample was imposed on the validation sample while all parameters were left free. Indices (χ^2=24.20, p=.019; NFI=.984; CFI=.993; RMSEA=.059) for the overall fit of this multi-group model were good (see Table 2). Using a more restricted approach (tight cross validation), structural invariance was also imposed to the validation sample, with all parameters constrained to the calibration model 4 loading values. Final results continued to show a good overall fit (χ^2=30.44, p=.010; NFI=.980; CFI=.990; RMSEA=.042), and the formal testing for differences between the imposed parameter's values showed no significant values. So, the solution found for the calibration sample (model 4) showed a very good adjustment to the other half of the data, proving its validity for interpreting the MC model.

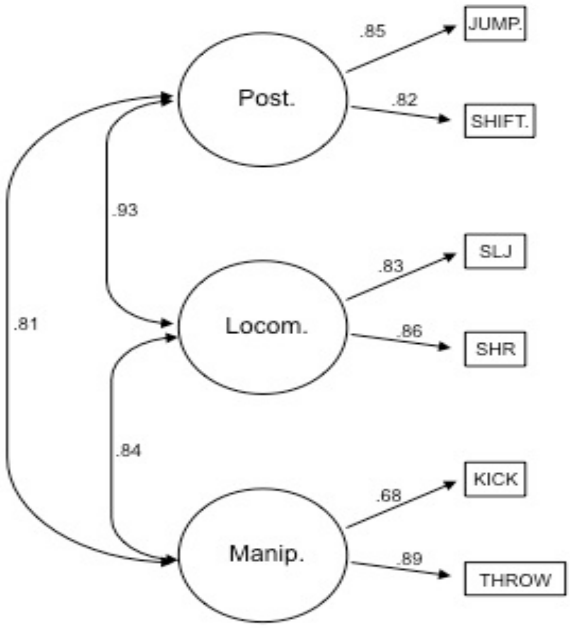

Figure 2 - Final MC model generated from SEM. Large circles represent latent factors, which are unobserved variables. Rectangles represent variables that were directly measured. Single arrows represent a one-directional effect from one variable to another, while dual-head arrows represent factor covariances. Standardized path coefficients are indicated by the numbers above the arrows and represent the correlation or strength of the relationship between factors.

Table 2 - Indices for evaluating goodness of fit of models in different phases

	χ^2	*p*	NFI	CFI	RMSEA
Phase 1 - Calibration sample (n=292)					
Model 1 (9 variables)	159.39 (24 *df*)	.000	.881	.896	.139
Model 2 (8 variables)	134.31 (18 *df*)	.000	.880	.894	.149
Model 3 (7 variables)	96.69 (11 *df*)	.000	.897	.907	.164
Model 4 (6 variables)	12.04 (6 *df*)	.061	.982	.991	.059
Phase 2 – Validation sample (n=292)					
Model 4 (6 variables)	12.15 (6 *df*)	.058	.986	.993	.059
Phase 3 - Multi-group analysis (n=584)					
Measurement invariance	24.20 (12 *df*)	.019	.984	.992	.042
Structural invariance	30.44 (15 *df*)	.010	.980	.990	.042

3. 4. Discussion

The aim of this study was to establish a model of MC, based on a theoretically structure divided into locomotor, stability, and manipulative domains. In this endeavour, quantitative (product-oriented) motor test protocols without a developmental (age) ceiling effect, and of feasible execution, were used. Our purpose when selecting only product-oriented tests was to ensure an objective evaluation and a good sensitivity to discriminate among competence levels across ages (Stodden et al., 2014).

The use of SEM for testing this specific model is of great utility since it allows to work from the data for reaching a final solution for a MC structure that represents well the communality (represented by the covariance) and the unique characteristics (non-explained covariance) of tests (items) and categories (factors). The overall adjustment indices, along with the individual coefficients for the paths involved (factor-item; factor-factor) provides a rationale for including or excluding each item (test), or factor (category), or path (representativeness of the tests to mark a category), to a better representation of the full model.

In the validation phase our results confirmed the existence of three latent factors representing the stability (shifting platform and jumping laterally), locomotor (SHR and SLJ), and manipulative (throwing Velocity and kicking Velocity) categories of MC, each one best represented by two of the initial three motor tasks chosen. These three factors show to reproduce very well three distinctive aspects of MC, as proved by the inexistence of any change suggested in the factor-item structure by the modification indices. In addition, and in accordance with the theoretical framework, these three categories (factors) proved to be closely related with each other. Overall, this model presented a very good fit to the data (Bentler, 2006; Byrne, 2006; Raykov & Marcoulides, 2006), suggesting that it can be used to represent (and assess) MC.

In the second phase, the replication of the initially found model structure resulted also in a very good fit to the other half sample data (calibration sample), indicating a good reliability of the model to reproduce MC data. In the last step we formally tested for measure and structural invariance between the two half-split samples, in order to cross-validate for measurement and structural invariance. In both cases, the tested model showed a very adequate fit, concluding for its overall validity for interpreting MC in children and adolescents.

Therefore, our results postulate that MC can be advantageously represented by locomotor (SHR and SLJ), stability (moving platform and jumping laterally), and manipulative (kick and throw velocity) categories of movement skills, and that the latent essence of each of these categories can be objectively measured by two quantitative motor tasks. This model presents several advantages for research, education, and clinical settings.

The first advantage is the use of a set of motor tasks widely used in past research settings as representative of MC categories (Gallahue et al., 2012; Kiphard & Schilling, 2007; Stodden et al., 2014). The second advantage is the parsimony of the model. Unlike other models' protocols that use several motor tasks, such as the TGMD (Ulrich, 1985) or M-ABC (Henderson & Sugden, 1992) or even some non-standardized protocols (Okely & Booth, 2004), our final model is only comprised by six feasible tests. The third advantage is that this model uses objective (quantitative) measures. Qualitative methods are focused on the process, providing insight into the form or characteristics of the movement; therefore, requiring a greater knowledge of the movement components and usually require a lot of time to analyse the data. Quantitative approaches are focused only on the final product and enable a faster assessment of the performance outcome with a high level of reliability over time (Spray, 1987). These methods are sensitive discriminators among competence levels across childhood and early adolescence (Stodden et al., 2014), and are correlated with qualitative process-oriented assessments of the skills (Mally, Battista, & Roberton, 2011; Stodden, Langendorfer, Fleisig, & Andrews, 2006a, 2006b). Moreover, quantitative methods also do not require a high level of expertise and training of the evaluators, as usually recommended in qualitative methods (Okely & Booth, 2004), since the lack of subjectivity inherent to the quantitative approaches permits that even less experienced observers can apply it. The entire protocol takes about 10 minutes per participant; however children can be grouped in small groups, reducing the average time needed for assessment. Furthermore, the results information can be immediately used, making it a huge advantage for the use in PE classes, and sports' environments. The fourth advantage is that the motor tasks used do not have a ceiling effect over developmental years, and so the same model and protocol can be used from childhood to adult years. The fifth advantage is that the model, giving the magnitude of the correlations between factors, suggests the possibility to obtain a global composite score of MC, in addition to the categories' scores.

This model is representative of MC and can be used by researchers, PE teachers, and health and sports training professionals, in order to objectively monitor motor development. This MC model seems promising, but further research is warranted to replicate the current results.

This study has some limitations. The results confirmed the agreement of six of them with the tested model, nevertheless, and in order to achieve a more accurate representation of MC, a broader range of motor tests could be warranted in next studies. In addition, in order to be consistent with the number of trials for each skill, the use of three trials could be more appropriate to select the best score.

It is also important to note that our sample had children from 6 to 14 years old and the results might even have a better adjustment for separate groups of age and gender. Future investigations should take into consideration age and gender.

3. 5. Conclusion

Our results support the idea that MC can be evaluated through a protocol with six motor tasks that represent the three major latent variables of MC (*i.e.*, stability, locomotor and manipulative). We suggest that the use of a quantitative approach with few motor tasks without a celling effect, which are representative of the major MC components, is a good alternative to the existing testing protocols. Because the tested motor tasks are easy to assess, PE teachers or even trained classroom teachers can use this model regularly in their practices and evaluations.

3. 6. Practical implications

- Brief and easy to administer evaluation model representative of MC, which can be used by several professionals to objectively monitor MC in several contexts.
- The teaching of motor skills should be integrated into the PE curriculum activities, and teachers could use this model protocol to assess children's MC.
- This regular assessment can help teachers to develop the best approach and exercises to improve their student's MC.

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CHAPTER 4

LINKS BETWEEN MOTOR COMPETENCE AND HEALTH RELATED FITNESS IN CHILDREN AND ADOLESCENT

Carlos Luz, Gabriela Almeida, Luis Paulo Rodrigues, Rita Cordovil

LINKS BETWEEN MOTOR COMPETENCE AND HEALTH RELATED FITNESS IN CHILDREN AND ADOLESCENT

Abstract

Objectives: This study examined Motor Competence (MC) behaviour in 6 to 14-year-old children, and investigated the differences in Health-related fitness (HRF) between high and low MC groups, according to gender and age.

Methods: A random sample of 564 children (288 males) participated in this study, which was divided into three age groups (6-8 years; 9-11 years; 12-14 years). MC was assessed using a quantitative MC instrument. Cardiovascular fitness was predicted by a maximal multistage 20-m shuttle-run test of the Fitnessgram Test Battery, and body composition was measured following standard procedures.

Results: MC increased across age groups for both genders but boys presented better results than girls in MC and respective components (except on stability in the middle age group). The high MC group outperformed their low MC peers in HRF, independently of their age group. Although MC proficiency increased with age for both the high and low MC groups, low proficiency children do not seem capable to catch up with their peers within the studies age range.

Conclusions: The findings suggest that MC interventions should be considered as an important strategy to enhance HRF, and girls should be a priority group since early age.

Keywords Motor competence; Health-related fitness; children; adolescents; high motor competence; low motor competence.

4.1. Introduction

Modern western society does not seem to fully understand the threat that the way of life of current children and adolescents poses to their present and future health and well-being. The overall prevalence of childhood obesity is high (Low et al., 2009), and children tend to spend less time and engage less in physical activity (PA), (Andersen et al., 2006; Strong et al., 2005) while spending more time in sedentary activities (Hills, King, & Armstrong, 2007; Lopes, Santos, Pereira, & Lopes, 2012). Central to this problem, motor competence (MC) and health related fitness (HRF) are showing a decline over the recent years (Catley & Tomkinson, 2011; Hardy, Barnett, Espinel, & Okely, 2013; Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012; Vandorpe et al., 2011). Stodden and colleagues' (Stodden et al.,

2008) theoretical model allocates a primordial role to MC for developing an active and healthy lifestyle, and just very recently, Robinson and colleagues (Robinson et al., 2015) proposed an update of the model based on the comprehensive interpretation of the effects of MC on the positive developmental trajectories of health. According to the latest research evidences, authors proposed that the strength of the relationship between MC and HRF, and MC and weight status, is high, increases with time, and is paramount for determining actual and future trajectories of health (Robinson et al., 2015). We also know that low MC children present higher body mass index (BMI) (Cantell et al., 2008) and lower physical fitness, and it appears to be increasingly difficult for these children to catch up to their peers weight status over time. Moreover, the difference between these two groups, regarding their physical fitness, tends to remain constant over time (Fransen, Deprez, et al., 2014; Hands, 2008).

MC is used as a global term that includes a wide variety of terms used in literature (*i.e.,* fundamental motor skill or movement, motor proficiency or performance, motor ability and motor coordination), and can be advantageously described as a person's ability to be proficient on a wide range of motor acts or skills (Fransen, D'Hondt, et al., 2014) that include locomotor, stability or manipulative movements (Gallahue et al., 2012; Luz et al., 2015). Emerging evidence indicates that object control/manipulative skills are more likely to be predictive of HRF in late childhood and early adolescence (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Stodden, Gao, Goodway, & Langendorfer, 2014) while for early stages of development the locomotor skills may have a more important role (Stodden et al., 2014).

Given these recent evidences it is vital to follow and understand the MC normative development of children over a wide time span, from childhood to adolescence, and to study how its relationship with the other model components, namely HRF and weight status, changes over time. A quantitative model to evaluate MC in children and adolescents, including three (locomotor, stability, and manipulative) components was recently proposed (Luz et al., 2015), but no descriptive or normative data is yet available.

Accordingly, the purposes of the present study were: i) to describe MC behaviour in a large sample of children with ages ranging from 6 to 14 years; and ii) to investigate the differences, according to gender and age, in physical fitness and body composition amongst two groups with differentiated MC (*i.e.,* higher and low MC).

It is presumed that boys will have better performances than girls in motor and physical fitness tests, independently of age, and that all performances should improve with age

(Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012; Ortega et al., 2014). It is also hypothesized that no significant gender dependence exists with BMI (D'Hondt et al., 2010; Lopes et al., 2012). Additionally, it is expected that the highest MC group will show better results on physical fitness tests and BMI, independently of age and gender, in comparison to the lowest MC group (Fransen, Deprez, et al., 2014; Rodrigues, Stodden, & Lopes, 2015).

4.2. Methods

Participants

A random sample of 564 children (288 males) aged 6 to 14 years old, with an average age of 10.6 years (SD=2.40) participated in this study. Children had no motor limitations and were selected from public schools. Two physical education teachers collected all the data for this study over a period of three months during regularly scheduled classes. A local ethics committee ensured that all procedures regarding scientific research involving human beings would be conducted safely. Written informed consent was obtained from the children's parents. Children were asked for verbal assent, while informed that participation was voluntary and that they could leave the study at any point.

Measures and Procedures

Health-related fitness

HRF comprises a number of different components, such as cardiorespiratory fitness, muscle strength, muscle endurance, flexibility, body composition (Hands, Larkin, Parker, Straker, & Perry, 2009). In this study three components of HRF were assessed, namely cardiorespiratory fitness (PACER), upper body strength (handgrip test) and body composition (BMI).

PACER test: This test assessed aerobic capacity by using a progressive shuttle run (20 meters) with an increased cadence. The FITNESSGRAM test protocol (for more information see Welk & Meredith, 2008) was used with one modification; to ensure that the participants reached their maximum level and to give proper encouragement, an adult ran with them to pace the rhythm.

Handgrip test: This test is often used for assessing muscular fitness in epidemiological studies (Ortega, Ruiz, Castillo, & Sjöström, 2008). Each participant squeezes the

dynamometer with maximum isometric effort, maintained for 5 seconds. The best result after 3 attempts was recorded as the final score.
Body composition: Participant's height and weight measures were used to calculate the BMI score.

Motor competence

Motor competence was evaluated using the model proposed by Luz and colleagues (Luz et al., 2015), developed on a sample of Portuguese children. The model is divided into 3 factors/categories (stability, locomotor and manipulative) with two motor tasks each:
Stability: a) Shifting platforms – moving sideways for 20 s using two wooden platforms (25 cm x 25 cm x 2 cm). Each successful transfer from one platform to the other is scored with two points (one for shifting the platform, the other for transferring the body). Participants were given two trials and only the best score was considered; b) Jumping laterally – jumping sideways over a wooden beam as fast as possible for 15s. Each participant was to jump with both feet together and to each correct jump was given 1 point. The total score was thus the largest number of jumps achieved in two trials.
Locomotor: a) Shuttle run (SHR) – The task was to run at maximum speed along lines placed 10 meters apart, then pick up a block of wood, and run back to place it on or beyond the starting line. Then they were to run back to retrieve the second block and carry it back across the finish line. The final score was the best time of two trials; b) Standing long jump (SLJ) – jump with both feet simultaneously as far as possible. Children were allowed to swing their arms back and forth. The final score was given by the longest (the best of both attempts) distance (in centimetres) between the starting line and the landing position.
Manipulative: a) Potency throws – throw a baseball (circumference: 22.86 cm; weight:142 g) at a maximum speed against a wall using an overarm action. Ball speeds were measured with a Pro II Stalker Radar Gun; b) Potency Kick – kick a soccer ball no. 4 (circumference: 64 cm, weight: 350 g) as hard as possible against a wall with a kicking motion. Ball speeds were measured with a Pro II Stalker Radar Gun.
For these two tasks, each participant had 3 attempts, and the final score was given according to the highest ball speed.
Stability, locomotor, and manipulative categories were calculated through the sum of the t-scores of the two representative tasks. However, in the locomotor category, since the best result in the SHR was the smaller value (time) we subtracted the two tasks.

Motor competence – As mentioned above, the MC evaluation should include tasks ranging stability, locomotor and manipulative categories (Gallahue et al., 2012), so the MC was measured from the sum of the three categories' outcomes (t-scores).

Procedures

All participants were evaluated in groups of five and in the same task order. The stability tasks were performed first, followed by the locomotor tasks and, lastly, the manipulative tasks. A proficient movement was demonstrated to all participants, and an opportunity was provided for them all to try each task out before their turn. Motivational feedback was given, but the results of the tasks were not commented on.

Data analysis

In the first part of this study all variables (MC and HRF) were described according to age (the sample was divided into three groups: 6-8 years; 9-11 years; 12-14 years) and gender. The 3 (age) × 2 (gender) ANOVA was computed to detect age and gender effects on MC.
In the second part of the study participants were divided based on MC tertile cut-points and two groups were considered, one with the lowest tertile score and the other with the higher tertile scores. Participants with intermediate scores were excluded from this analysis. A multivariate analysis of variance (MANOVA) using pacer, handgrip strength, and BMI as multivariate dependent variables was conducted for both genders, to test for age and MC groups effects on health related fitness measures.
A $p<.05$ was used as the level of statistical significance for all statistical analyses which were conducted using SPSS 20.

4.3. Results

Descriptive statistics for PACER, handgrip, BMI, MC and the three components of MC for each age group, divided by gender, are displayed in Table 3. The analysis of variance (ANOVA) revealed significant main effects of gender and age groups in all MC variables; boys generally outperformed girls in all variables. Moreover, both genders exhibited, on average, an overall increase of MC as well on all MC components with age development.

Table 3 - Means and standard deviations for MC and HRF variable by age group and gender.

	6-8 yrs		9-11 yrs		12-14 yrs	
	B = 94	G = 90	B = 97	G = 94	B = 97	G = 92
Stability (pts)	M/SD	M/SD	M/SD	M/SD	M/SD	M/SD
Locomotor (pts)	43.5/7.0	41.3/7.1	49.2/7.6	50.8/8.0	59.1/8.2	55.5/9.1
Manipulative (pts)	46.3/6.6	40.5/7.9	50.7/8.0	48.6/7.0	61.1/8.8	52.0/8.3
MC (pts)	46.0/4.9	38.3/4.8	53.7/6.0	46.2/4.9	64.3/8.6	50.4/5.6
PACER (laps)	44.6/5.8	38.8/6.2	51.4/6.5	48.4/6.0	62.9/8.2	53.0/7.0
Handgrip (Kgf)	31.8/12.6	23.1/9.0	35.7/16.0	30.9/11.9	49.1/19.0	32.8/14.6
BMI (Kgm-1)	10.4/2.7	10.0/2.7	14.9/4.1	14.6/4.1	25.3/7.4	22.9/4.7
Stability (pts)	17.0/1.9	17.4/2.5	19.4/3.7	18.7/3.4	20.3/3.7	21.9/4.7

yrs - years

Additionally, significant interaction effects for all MC measures were found (see Figure 3). More specifically, the results show a significant interaction between gender and age group for stability (F(2, 558)=5.53, *p*=.004, η^2p=.019), locomotor (F(2,558)=9.30, *p*<.001, η^2p =.032), and manipulative (F(2,558)=17.67, p<.001, η^2p =.060) skills and MC (F(2,558)=13.07, *p*<.001, η^2p =.045). Therefore, both genders displayed different age development rates for all MC variables. To summarise, boys exhibited a slower increase in MC between the younger and intermediate group and a faster one after this period (*i.e.,* larger slope from the middle to the older group), whereas girls showed inverse tendencies. In addition, large differences in the manipulative components are present between the genders, independently of age. For the second part of the study the sample was divided into tertiles based on MC scores and only the highest and the lowest groups, for each gender, were considered for the analyses of the multivariate HRF results (Table 4). The one-way MANOVA results for boys revealed significant main effects for MC groups, Wilks' λ = .479, *F* (3,182) = 65.88, *p* <. 001, η^2p = .521; and for age groups, Wilks' λ = .285, *F* (6,366) = 52.93 *p* <. 001, η^2p = .466, and a significant interaction effect between age and MC groups Wilks' λ = .842, *F* (6,364) = 5.46 *p* <. 001, η^2p = .083. Girls also displayed significant main effects for MC groups Wilks' λ = .577, *F* (3,175) = 43.70 *p* <. 001, η^2p = .423; and for age groups Wilks' λ = .254, *F* (6,350) = 57.31 *p* <. 001, η^2p = .496, however no significant interaction effect for these variables was found. According to these results, the more proficient MC group consistently displayed better HRF results, for both genders, and the MC results increased with age (see Table 4).

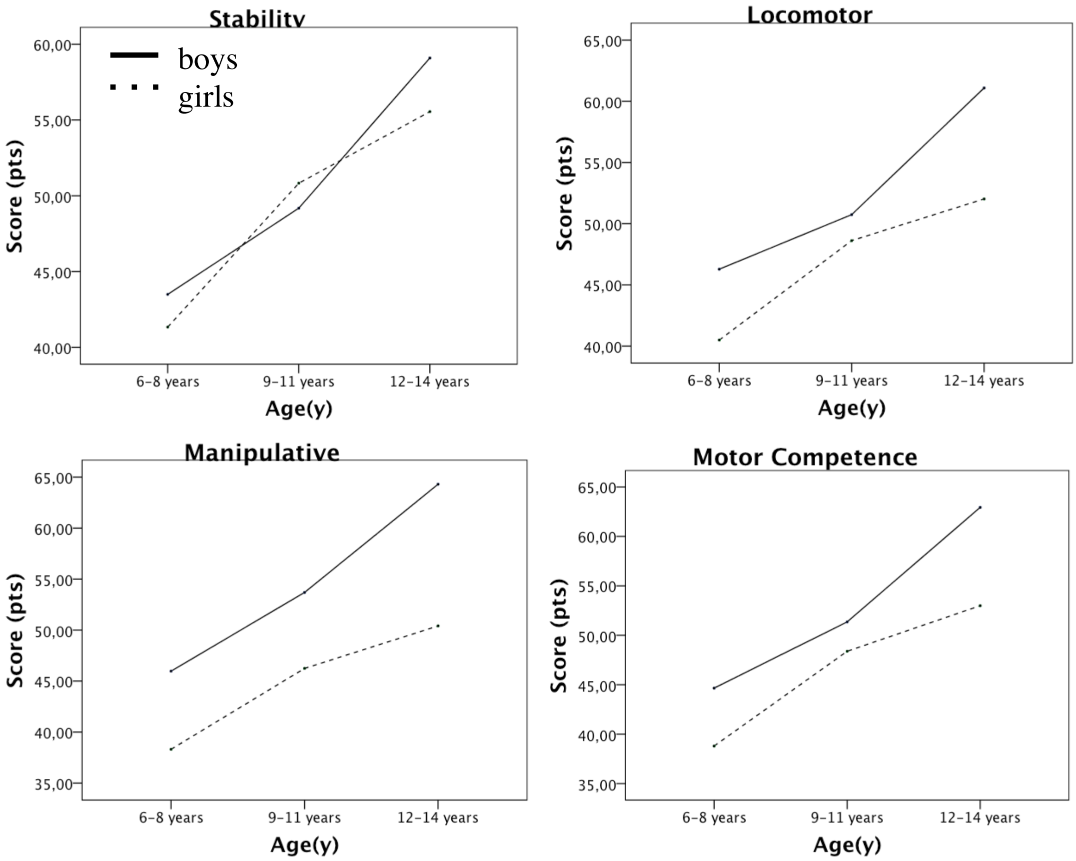

Figure 3 - Evolution of the means of MC and respective components for boys and girls across age groups.

Table 4 - Means and standard deviations for high and low MC groups in HRF variables by age group.

Boys						
	6-8 yrs		9-11 yrs		12-14 yrs	
	High (n=31)	Low (n=31)	High (n=32)	Low (n=32)	High (n=32)	Low (n=32)
Variables	M/SD	M/SD	M/SD	M/SD	M/SD	M/SD
PACER	41.5/11.0	23.9/9.5	45.8/14.3	24.6/10.5	62.3/17.4	35.4/14.7
Handgrip	11.8/2.7	9.0/2.4	15.4/3.6	13.7/4.2	29.7/6.5	21.1/6.6
BMI	16.8/1.8	17.2/2.4	17.5/1.9	21.0/4.0	20.1/3.1	20.7/4.7
Girls						
	6-8 yrs		9-11 yrs		12-14 yrs	
	High (n=30)	Low (n=30)	High (n=31)	Low (n=31)	High (n=31)	Low (n=30)
Variables	M/SD	M/SD	M/SD	M/SD	M/SD	M/SD
PACER	29.0/10.3	17.7/4.4	38.1/12.4	26.4/9.9	42.6/13.6	24.4/11.6
Handgrip	11.5/2.8	8.7/2.4	15.4/3.9	13.1/3.6	24.4/4.8	22.1/4.7
BMI	17.1/2.0	17.8/3.0	17.6/2.6	18.9/3.1	20.2/2.8	23.7/5.4

Pacer – laps; Handgrip - Kgf; BMI - Kgm-1; yrs - years

To further clarify these results, univariate main effects were examined for both genders. Boys and girls displayed a significant main effect for MC tertile group (all *p*-values < .001) and age (all *p*-values < .001) in all tested variables (see Figure 4). Therefore, these results show that in both genders the most proficient group displayed always significantly better values for all individual variables (PACER, handgrip and BMI) and each variable increased significantly across the age groups. It is interesting to notice that, in both genders, for the PACER test, the difference between the groups increased with age, meaning that the MC groups became more distinct on PACER performance as the children got older.

4.4. Discussion

In this study we have investigated the relations between MC, physical fitness, and body composition of children between the ages of 6 and 14 years. The results were evaluated according to age and gender and revealed that boys tend to outperform girls in all variables, independently of age (Table 3). These results are in line with other published studies. For example, similar results for MC and cardiovascular fitness were found in children from 6 to 14 years of age (Lopes et al., 2012), for BMI in childhood and adolescents (Hands, Larkin, Parker, Straker, & Perry, 2009; Lopes et al., 2012; Martins et al., 2010), and for the handgrip test (Cohen et al., 2010; Ortega et al., 2014).

Additionally, it was interesting to observe that the intermediate age group (9-11 years old) presented more similarities between genders than the other age groups. Biological maturity refers to progress towards a mature state with several physical changes, and this could explain these results. Girls, on average, mature around the age of 12, approximately two years before boys do (Malina, Bouchard, & Bar-Or, 2004); therefore, more similar results are expected to appear in this age group.

Furthermore, both genders showed better results on MC as the subjects got older. These findings show a better integration of sensory and motor systems with age, being consistent with Gallahue and colleagues' (2012) theoretical framework and other studies (D'Hondt et al., 2013; D'Hondt et al., 2010; Hands, 2008; Stodden, Gao, Langendorfer, & Goodway, 2014). On the other hand, the increase in motor variable performances with age was not consistent for both genders, since a significant interaction effect was found between gender and age group for MC and its different components (Figure 3). Therefore, in some ages the growth rate for boys and girls is greater than in others, and it is interesting to notice that girls present a faster growth rate (slope) between the first two groups and boys between the two elderly groups for all motor variables.

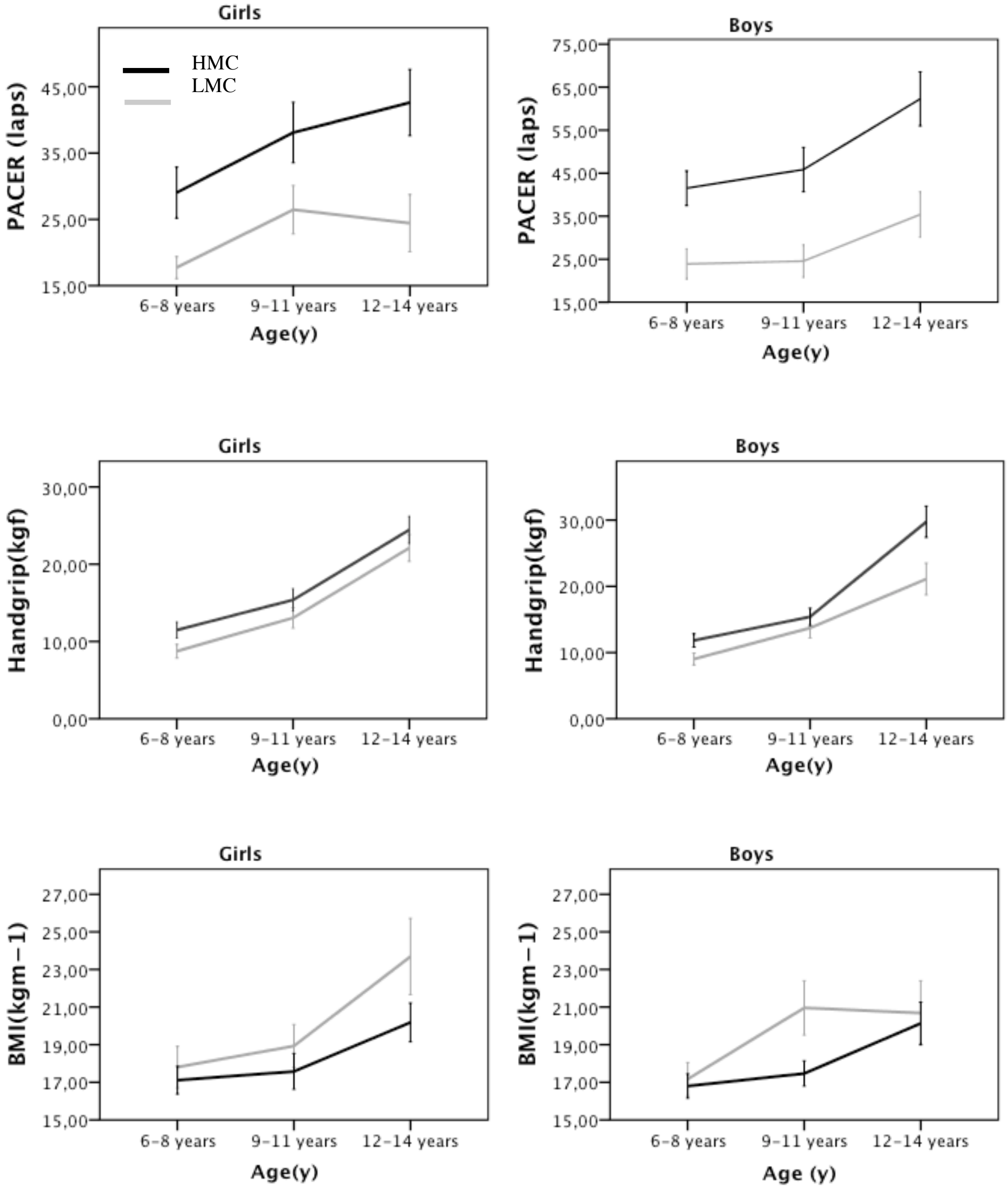

Figure 4 - Means evolutions and 95%CI for all HRF variables in both genders. HMC – high motor competence; LMC –low motor competence

As mentioned above, reaching a mature stage is followed by several physical changes and it seems that reaching this mark affects motor variables and could help explain the results. Moreover, and in accordance with Thomas and French (1985), the higher gender difference across childhood and adolescence for the MC related variables was found for the manipulative component (see F values in table 3) and may be explained by different reasons: 1) there is a higher incidence of locomotor and postural goals in primary schools' physical education programs, as also mentioned by Barnett, van Beurden, Morgan, Brooks, & Beard (2010), which highlights the importance of informal activities and formal sports in the development of the manipulative component during this stage; 2) the existence of stereotypical cultural practices (*i.e.,* informal activities) that favour specific play practices (boys are generally more involved in activities with balls) and therefore the development of certain movement skills, are different between genders (Giagazoglou et al., 2011; Junaid & Fellowes, 2006; Morley, Till, Ogilvie, & Turner, 2015); 3) the Portuguese formal sports culture includes approximately 80% of children and adolescents who play sports with manipulative objects (*e.g.*, soccer, handball, volleyball) and about 90% of these athletes are boys (IPDJ, 2015); 4) there is a stronger social support system and motivation towards physical activities for boys (Kourtessis et al., 2008); 5) high levels of effort and complex organization of intramuscular and intermuscular multisegment coordination and control are necessary to produce higher performances in manipulative skills (Stodden et al., 2012; Stodden, Langendorfer, & Roberton, 2009); and 6) biological influences on development (Thomas, Alderson, Thomas, Campbell, & Elliott, 2010; Young, 2009). These gender differences found for manipulative tasks are in line with several studies (Barnett et al., 2010; Butterfield, Angell, & Mason, 2012; Junaid & Fellowes, 2006) as well the trends of age development of throwing tasks (Butterfield et al., 2012; Thomas & Marzke, 1992).

All motor variables were shown to present higher gender differences in the older group comparatively to the younger group. Studies with younger children have found a similar trend (Morley et al., 2015), reinforcing the idea that gender differences increase from childhood to adolescence and older children become biologically more distinct than younger ones.

In the second part of this study and as hypothesized, we found a strong effect of the MC groups on HRF, that is, the more proficient MC group showed better HRF results than their low proficient MC peers, and this effect was consistent across age groups and for both genders. We have also found an age group effect for each MC proficiency group with usually higher results in the older group. Moreover, when looking for HRF variables we found that the gap values for cardiovascular fitness between high and low MC groups increased with age (figure 4 and table 4), indicating that proficiency groups tend to become more different during growth. Previous works found similar results for cardiovascular fitness (Fransen, Deprez, et al., 2014; Haga, 2009; Hands, 2008), handgrip in the younger age group (Fransen, Deprez, et al., 2014) and BMI (D'Hondt et al., 2010, 2014; Rodrigues et al., 2015). Longitudinal studies confirmed that children with low MC are unlikely to catch up to their peers in time (Fransen, Deprez, et al., 2014; Haga, 2009; Hands, 2008). Additionally, it is well established that high MC children spend more time doing physical activities (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009a; Wrotniak et al., 2006), and participating in sports (Fransen, Deprez, et al., 2014). Therefore, it is of paramount importance to promote the development of MC from an early age in order to decrease the possibility that children will develop negative trajectories of MC and health- related fitness, avoiding also health and social problem that derive from overweight and obesity (Rodrigues et al., 2015).

To our knowledge, the current study is the first to assess MC in childhood and adolescence for both genders using an instrument (Luz et al., 2015) developed to include the three theoretical components proposed by Gallahue and colleagues (2012). The study has some limitations, such as its cross-sectional nature, which makes it impossible to indicate causality between MC and other variables. Therefore, longitudinal and interventional studies are needed to be able to better understand these relationships. The absence of maturational information is another limitation. Biological maturation influences all variables, mostly during the transition from childhood to adolescence; so, future studies should consider the inclusion of variables that allow determining the level of biological maturation of children. Another limitation of this study is related with the fact that muscular strength was assess using the handgrip task only, which assesses the strength of the upper body only. Other variables, such as the vertical jump, should have been included to assess leg strength.

4.5. Conclusion

The results of this study show that children with ages from 6 to 14 years display improved results in all motor variables with age and that boys generally present significantly better results than girls. However, the intermediate age group displayed smaller differences amongst genders. Additionally, significant interaction effects per gender and group age were found for all motor components. Therefore, it seems that genders displayed different growth patterns.

Although significantly different HRF values (mostly higher) were found across ages for both MC proficiency groups, children with high MC proficiency displayed always better results comparatively to children with low MC proficiency in all HRF variables, independently of genders. School-based interventions should consider MC as a key strategy to enhance health promotion.

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CHAPTER 5

THE RELATIONSHIP BETWEEN MOTOR COMPETENCE AND HEALTH-RELATED FITNESS IN CHILDREN AND ADOLESCENTS

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THE RELATIONSHIP BETWEEN MOTOR COMPETENCE AND HEALTH-RELATED FITNESS IN CHILDREN AND ADOLESCENTS

Abstract

Objectives: This study analyses the associations between motor competence (MC) and its components with health-related fitness (HRF) and body composition.

Methods: These variables were assessed in a random sample of 546 children (278 males) divided into four age groups (7-8 years; 9-10 years; 11-12 years; 13-14 years). A quantitative MC instrument, a maximal multistage 20-m shuttle-run test of the Fitnessgram Test Battery and the handgrip test were used to evaluate MC and HRF (cardiovascular fitness and upper body strength), respectively. Body composition was measured following standard procedures. Pearson bivariate correlations and standard regression modelling for the entire sample, and for each age group by gender, were used to explore the associations between motor and health-related fitness variables.

Results: Several significant moderate to high correlations between MC and HRF and an inverse correlation between MC and body composition were found for both genders. However the strength of the correlations was not, as hypothesized, larger in the older age group. The MC model explained 75% of the HRF variance, with the locomotor component being the highest predictor for the entire sample. When analysed for each age group and by gender, different predictors emerged, but stability skills were the higher predictor for both genders in the two older groups.

Conclusions: These results support the idea that the relationship between MC and HRF is strong and may change across childhood, and the development of stability skills in childhood may be important for HRF performances across childhood and into adolescence.

Keywords

Motor competence; health-related fitness; children; adolescents; correlations.

5.1. Introduction

In the past few decades, several worldwide alarming findings concerning children's holistic development have been found. Nowadays, children spend more time engaging in sedentary behaviours (Hills, King, & Armstrong, 2007; Lopes, Santos, Pereira, & Lopes, 2012), and tend to spend less time in physical activity (Andersen et al., 2006; Strong et al., 2005). Moreover, children's motor competence (MC) and health related fitness (HRF) are showing a decline over the recent years (Catley & Tomkinson, 2011; Hardy, Barnett, Espinel, & Okely, 2013; Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012; Vandorpe et al., 2011), and an alarming high prevalence of childhood overweight and obesity has also been found (Low et al., 2009). Recent research emphasises the paramount importance of MC for developing an active and healthy lifestyle (Cattuzzo et al., 2015; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Robinson et al., 2015; Stodden et al., 2008). For example, several cross-sectional and longitudinal studies found positive associations among MC and physical activity (Holfelder & Schott, 2014; Lubans et al., 2010b), HRF (Haga, 2008; Stodden, Gao, Goodway, & Langendorfer, 2014; Vedul-Kjelsås, Sigmundsson, Stensdotter, & Haga, 2012), and an inverse association between MC and weight status (D'Hondt et al., 2010, 2014; Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012). Additionally, MC is found to be an important predictor of physical activity in childhood (Lopes, Rodrigues, Maia, & Malina, 2011) and adolescence (Barnett, van Beurden, Morgan, Brooks, & Beard, 2009b).

The theoretical model developed by Stodden and colleagues (2008) proposes a reciprocal and developmentally dynamic relationship between MC and HRF with an increasing strength of this relationship over time. A recent study found an increase of the correlations strength between manipulative skills and HRF over time, therefore this skills may play a fundamental role in the increase of the strength of the association between MC and HRF (Stodden et al., 2014). Moreover, Robinson and colleagues' (2015) review supports the model hypotheses regarding the associations among variables. However they did not find conclusive evidence that these associations become stronger with increasing age.

MC is a global term relating to development and performance of human movement (Stodden et al., 2008) and is used as a global term that comprehends the wide variety of terms previously used in literature (*i.e.*, fundamental motor skill or movement, motor proficiency or performance, motor ability and motor coordination) (Robinson et al., 2015) . Moreover, MC can be described as a person's ability to be proficient on a broad range of motor acts or skills (Fransen, D'Hondt, et al., 2014), that include locomotor, stability and manipulative skills as proposed by the theoretical framework developed by Gallahue, Ozmun & Goodway (2012).

The purpose of this study was to analyse the interrelationships among MC and its components, HRF, and body composition in a large sample of children from 6 to 14 years.

It is hypothesized that MC will be positively associated with HRF (with greater strength in older age groups) and negatively associated with BMI (Robinson et al., 2015; Stodden et al., 2008). Moreover, based on a study by (Stodden, Gao, Goodway, & Langendorfer, 2014), manipulative skills are expected to have a prominent role in the associations between MC and HRF (Barnett, Van Beurden, Morgan, Brooks, & Beard, 2008; Stodden et al., 2014). To our knowledge, this study is the first to examine this variables using a quantitative instrument (Luz et al., 2015) with good validity that provides an MC composite from the three theoretical components (*i.e.*, locomotor, stability and manipulative skills) (Gallahue et al., 2012).

5.2. Methods

Participants

A random sample of 546 children (278 boys, 50.9%) with a mean age of 10.77 years (SD=2.3; range 7-14 years) participated in this study. The entire sample was divided into 4 age groups (2 years interval, see Table 1) for further analyses. Children were selected from public schools of different municipalities in the Lisbon district and had no motor or health restrictions that could affect the realization of any of the motor skill or fitness tests. Two physical education teachers collected the data for this study during regularly scheduled classes. The local ethical committee ensured the conformity procedures regarding scientific research involving human beings. Written informed consent was obtained from schools and children's parents of all participants before participation.

Measures and Procedures

Health-related fitness

The PACER and the handgrip test were used to evaluate cardiorespiratory fitness and upper body strength, respectively. The PACER test is a progressive shuttle run (20 meters) test protocol with increased cadence (Welk & Meredith, 2008) with one modification. To enable participants to reach their maximum level and to give proper encouragement, an adult ran with them to establish the rhythm. The handgrip test is a commonly used test for assessing muscular strength (*e.g.*, Ortega, Ruiz, Castillo, & Sjöström, 2008). Each participant starts from a standing position and grabs a standard dynamometer for 5 seconds using maximum strength with the dominant hand. The best result after 3 attempts was recorded as the final score. An overall HRF index was calculated from the mean of the T-scores of the two physical fitness components as measured with the PACER test and the handgrip test.

Motor competence

MC was evaluated with a valid quantitative instrument developed by Luz and colleagues (2015). This instrument has 2 tasks per category (stability, locomotor and manipulative): Stability: a) Shifting platforms – Moving sideways on wooden platforms for 20s; b) Jumping laterally – jumping sideways over a wooden beam with both feet as fast as possible during 15s. Locomotor: a) Shuttle run (SHR) - run forward and back (10 meters) two times at maximal speed retrieving 2 blocks of wood; b) Standing long jump (SLJ) – jump with both feet simultaneously as far as possible. Children can swing the arms back and forward. Manipulative: a) Potency throws – throw a baseball at a maximum speed against a wall using an overarm action; b) Potency Kick – kick a soccer ball nº 4 at a maximum speed against a wall using a kicking action. Ball speeds in both tasks were measured with a Pro II Stalker Radar Gun (for detail information see Luz et al., 2015).
Stability, locomotor and manipulative categories were calculated through the sum of the t-scores of the two representative tasks. However, in the locomotor category, since the better result in the SHR is the smaller value (time) we subtract the two tasks. MC was measured through the sum of t-scores of the 3 categories outcomes.

Body composition

Participants' height and weight were measured and used to convert to body mass index (BMI) score.

Procedures

The same test protocol was used for all participants: children completed the tests in groups of five, starting with the stability tasks, followed by the locomotor tasks and the manipulative tasks respectively. The PE teacher demonstrated the proficient technique of all tasks and participants were allowed to try out each task once before the actual test administration. Motivational feedback was given; however no verbal feedback on skill performance was provided. Moreover, two testing sessions on separate days were needed to complete the HRF and MC tests.

Data analysis

Descriptive statistics (means and standard deviations of the t-scores) were calculated to characterize each MC, HRF and BMI by age groups and gender. Pearson's bivariate correlations were calculated to assess the relationships among motor, HRF and BMI variables. Then, to test if the relationships amongst HRF and MC differed across age groups, a one-way analysis of covariance (ANCOVA) was conducted with HRF as dependent variable, age group as independent variable, and age by manipulative, age by stability, and age by locomotor as covariates. A hierarchical multiple regression analysis was performed with all participants to measure the predicted explained variance of MC components (independent variable) for HRF (dependent variable) after controlling for age and gender. Separate standard regressions analyses for each age group's HRF were conducted using individual MC components as predictors. All statistical analyses were conducted in SPSS version 20 and the level of significance was defined as lower than 0.05.

5.3. Results

Descriptive data indicated that all variables increased across age groups in both genders (see Table 4). Correlations among motor, HRF and body composition variables are presented in Table 5. In general, significantly moderate to high correlations between MC and HRF (.49 to .71) were found for both genders in all age groups. However, some differences exist between genders across age groups, MC and HRF were for example strongly correlated in 11-12 year old boys (.71) but only weakly correlated in girls of the same age group (.49). A difference in the opposite direction was found among 7-8 year olds with boys displaying weaker associations between MC and HRF than girls. The results also showed that all MC components displayed significant associations with HRF, but with different strengths for both genders. For boys, manipulative (.67) and locomotor (.62) components displayed higher associations for the two younger groups, respectively, and stability showed better relationship for the two older groups (.68 and .70). Girls present similar result for the older group with stability component displaying the higher association (.61); however, the locomotor component presented higher associations for all the other age groups. For boys, the highest associations amongst motor and HRF variables were found between MC and the HRF (.71), and for girls, between the locomotor component and HRF (.97). Moreover, significant inverse associations (weak to moderate) with BMI were found in the two middle-aged groups for boys, and in all groups except the younger age group for girls. Interestingly, similar results were found for the association of BMI with the locomotor and stability components, but the manipulative component displayed only one significant association in the younger group for girls.

ANCOVA analyses revealed significant effects for all covariates, namely age by stability ($F(1, 529) = 24.90$, $p < .001$), age by locomotor ($F(1, 529) = 69.45$, $p < .001$), and age by manipulative ($F(1, 529) = 69.62$, $p < .001$). Consequently, to further investigate the relation between HRF and MC and its respective components, multiple regression analyses were performed for the entire sample and for the different age groups.

In the first phase of the standard multiple regression, the results showed (see Table 7) that gender and age were significant predictors for HRF and this model explained 56% of the HRF variance. Moreover, the variance explained increased to 75% when the three motor components were included in the model (Table 7).

In the second phase all variables except gender were significant predictors of HRF with the locomotor component displaying the highest predictor value. Additionally, standard regressions were performed for each age group and by gender with the MC components as independent variables (see table 8).

Although gender was not a significant predictor it was decided to run separate analyse for both genders since several studies mentioned significant gender differences in MC and HRF from early ages (Cohen et al., 2010; Hands, Larkin, Parker, Straker, & Perry, 2009; Laukkanen, Pesola, Havu, Sääkslahti, & Finni, 2014; Lopes, Santos, Pereira, & Lopes, 2013; Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012; Ortega et al., 2014).

Boys displayed the highest explained variance of HRF in the oldest ($R^2 = 56\%$), and the youngest age group ($R^2 = 54\%$) while the explained variance was lower in the two middle age groups (46% and 51% respectively). Manipulative and locomotor components were the highest predictors in the two younger age groups and the stability component in the two older age groups. Additionally, stability in the younger age groups, manipulative in the 11-12 year-old group, and locomotor in the two older age groups were not significant predictors of HRF.

Table 5 – Descriptive statistics for the 4 aged group by gender

	7-8 yrs		9-10 yrs		11-12 yrs		13-14 yrs	
	B = 81	G = 79	B = 72	G = 71	B = 66	G = 54	B = 59	G = 64
Var.	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Stability	43.5±7.0	41.1±7.3	48.4±7.9	49.5±8.5	53.1±7.5	51.4±6.6	60.8±8.8	57.2±9.5
Locomotor	46.2±6.6	40.5±8.1	50.2±7.6	47.3±7.2	54.9±9.2	50.3±8.1	62.9±8.8	52.0±8.1
Manipulative	46.0±5.3	38.1±4.9	52.4±5.8	44.4±4.5	58.4±6.9	48.2±4.2	66.5±8.7	51.0±5.8
MC	44.6±5.8	38.6±6.5	50.3±6.3	46.8±6.0	56.2±7.7	49.9±5.6	65.1±8.4	53.8±7.1
HRF	45.3±4.9	42.2±3.6	49.1±5.1	46.7±4.2	53.6/±7.2	50.4±5.0	62.9±8.5	54.5±4.6
BMI	17.1±1.9	17.5±2.5	19.0±3.4	18.7±3.3	20.1±3.5	20.2±4.7	20.5±3.9	22.1±4.4

Note: B = Boy, G = Girl. M = mean; SD = standard deviation; yrs – years; Stability – pts; Locomotor– pts; Manipulative – pts; MC – pts; HRF – pts; BMI - (Kgm-1)

Table 6 – Pearson correlations between motor competence, HRF and BMI in both genders by age groups. Boys below principal diagonal and girls above principal.

	7-8 yrs						**9-10 yrs**					
Variables	1	2	3	4	5	6	1	2	3	4	5	6
1. Stability	-	.69***	.46***	.88***	.60***	-.10	-	.59***	.40***	.91***	.47***	-.29*
2. Locomotor	.46***	-	.49***	.90***	.97***	-.17	.55***	-	.13	.80***	.60***	-.31**
3. Manipulative	.44***	.57***	-	.71***	.54***	.30**	.32***	.37***	-	.55***	.37***	.14
4. MC	.81***	.84***	.79***	-	.73***	-.04	.83***	.84***	.66***	-	.62***	-.26*
5. HRF	.48***	.60***	.67***	.71***	-	-.08	.40***	.62***	.49***	.64***	-	-.20
6. BMI	-.04	-.21	.13	-.07	-.05	-	-.53***	-.35**	-.10	-.44***	-.25*	-
	11-12 yrs						**13-14 yrs**					
1. Stability	-	.40**	.40**	.78***	.28*	-.45***	-	.51***	.38**	.84***	.61***	-.31*
2. Locomotor	.80***	-	.44**	.84***	.57***	-.51***	.64***	-	.49***	.84***	.56***	-.48***
3. Manipulative	.57***	.45***	-	.70***	.20	-.19	.51***	.54***	-	.70***	.43***	-.06
4. MC	.92***	.90***	.75***	-	.49***	-.53***	.85***	.87***	.81***	-	.68***	-.38**
5. HRF	.68***	.64***	.50***	.71***	-	-.20	.70***	.51***	.59***	.71***	-	-.07
6. BMI	-.37**	-.45***	.20	-.27*	-.19	-	-.21	-.36**	.02	-.22	-.06	-

Note: **p* < .05. ***p* < .01. ****p*<.001; yrs – years; Stability – pts; Locomotor– pts; Manipulative – pts; MC – pts; HRF – pts; BMI - (Kgm-1)

Table 7 – Multiple regression for MC components to HRF for the entire sample.

Step	Predictors	β	T	F	R^2
1				340.00***	.56
	Age	.708	24.64***		
	Gender	-.268	-9.33***		
2				308.93***	.75
	Age	.276	8.24***		
	Gender	-.024	-.80		
	Stability	.174	4.93***		
	Locomotor	.294	8.30***		
	Manipulative	.264	6.17***		

*p < .05. **p < .01. ***p<.001

In general, manipulative skills were significant predictors in three age groups and locomotor and stability only in two age groups. Girls presented the higher explained variance of HRF in the younger age group (R^2 = 55%) followed by the older age groups (R^2 = 46%). Relatively to significant predictors across age groups, the results showed that stability skills were the best predictor of HRF in the older group and locomotor skills were significant predictors for all the other age groups. Moreover, locomotor skills were significant predictors in all age groups, manipulative in two age groups and postural only in one age group. Generally both genders presented differences in the explained variance of HRF and also presented few similarities in terms of predictors across age groups.

5.4. Discussion

This study investigated the interrelationships among MC, an HRF index and body composition, according to 4 age groups and gender, in a large sample of children from 7 to 14 years. The results showed positive moderate to high associations between MC and HRF, regardless of age or gender. These associations were consistent with or even higher results from previous research (*e.g.*, Castelli & Valley, 2007; Erwin & Castelli, 2008; Haga, 2008; Vedul-Kjelsås et al., 2012). Physical activity experiences may have a key role as an underlying factor and could potentially explain this relationship as a higher frequency and intensity of physical activities positively influences the development and maintenance of both MC and HRF (Haga, 2008; Vedul-Kjelsås et al., 2012). Moreover, superior MC enhances the possibilities of participation in various physical activities (Wrotniak et al., 2006). Since multiple aspects of neuromuscular development are integrated into both MC and HRF, these associations probably reciprocally influence each other (Robinson et al., 2015). In addition, we found a lowest association between MC and HRF for girls in the 11-12 year old group, indicating that reaching a mature stage (several physical changes) in girls can affect this relationship, considering that girls reach maturity around 12 years of age (Malina et al., 2004).

Table 8 – Standard regression of MC components on HRF by gender and age groups.

	Boys				**Girls**			
	7-8 years							
	β	T	F	R^2	β	T	F	R^2
			28.88***	.54			29.83***	.55
Stability	.158	1.73			.171	1.54		
Locomotor	.274	2.72**			.452	4.01***		
Manipulative	.443	4.42***			.245	2.68***		
	9-10 years							
	β	T	F	R^2	β	T	F	R^2
			19.52***	.46			17.24***	.44
Stability	.027	.25			.052	.42		
Locomotor	.531	4.51***			.531	4.60***		
Manipulative	.295	3.05***			2.64	2.58*		
	11-12 years							
	β	T	F	R^2	β	T	F	R^2
			21.50***	.51			8.27***	.33
Stability	.373	2.33*			.088	.67		
Locomotor	.270	1.83			.569	4.25***		
Manipulative	.166	1.54			-.083	-.62		
	13-14 years							
	β	T	F	R^2	β	T	F	R^2
			21.50***	.56			16.97***	.46
Stability	.541	4.40***			.404	.3.54***		
Locomotor	-.004	-.03			.274	2.27*		
Manipulative	.316	2.81***			.149	1.35		

*p < .05. **p < .01. ***p<.001

In contrast with the initial hypothesis, the present study also showed that the relationship between MC and HRF is variable across time in both genders. A tendency towards a strengthening correlation between MC and HRF over time was not found, as opposed to what is advocated in the theoretical model proposed by Stodden and colleagues (2008). Recently Stodden and colleagues (2014) presented findings in support of the developmental model, however the authors did not present an MC composite but only two manipulative tasks and one locomotor task. Moreover, previous studies (Castelli & Valley, 2007; Erwin & Castelli, 2008; M Haga, 2008; Vedul-Kjelsås et al., 2012), did not find a clear tendency towards a strengthening relationship between MC and HRF. In a more recent study, weak associations using the same instruments were found for adolescents (Gísladóttir, Haga, & Sigmundsson,

2014) in comparison with children (Haga, 2008). Several doubts still remain concerning this matter, so more research is needed to gain a deeper understanding. Stodden and colleagues attributed the strengthening of the relationship between MC and HRF over time to the increased strength of the association between manipulative skills and HRF (Stodden et al., 2014). However, in our study this tendency did not appear; instead variable results across ages were found for manipulative skills, with the highest scores in the younger group for both boys and girls. Nevertheless, we found a tendency to higher correlations for locomotor and stability skills than for manipulative skills, in all age groups for both genders, except in the youngest boys. To our knowledge, few studies analysed the relationship between the different MC components and HRF and our results are in line with previous research concerning manipulative and balance components (Gísladóttir et al., 2014; Haga, 2008). However we did not find any studies that analysed the locomotor component.

Multiple regression analyses on the entire sample showed that MC performance predicted explained variance for HRF. These findings are similar to the results obtained by Stodden and colleagues (Stodden et al., 2014). However, our findings present higher explained predicted variance in both steps of the regressions, showing the close relationship that exists between MC and HRF. Interestingly, locomotor skills present the highest explained variance, contrary to what had been previously reported for a similar population (Stodden et al., 2014) but in line with results found in young adults (Stodden, Langendorfer, & Roberton, 2009). One important finding was that some differences emerge between genders across age groups with different predictors and values. For boys, manipulative skills are the most frequent predictor across age groups, but the skills only present the higher predictor value in the younger group. However we did not find higher predictor values across age groups for manipulative skills has it was previously mentioned (Stodden et al., 2014). On the other hand, for girls, locomotor skills are a significant predictor in all age groups, but with variable results. Interestingly, both genders present the same highest predictor in the two older age groups (*i.e.*, stability skills). Therefore, our results did not support Barnett and colleagues' (2008) suggestion that manipulative skills are the better indicator to explain associations between MC and HRF across childhood and into adolescence. It seems logical that manipulative skills are essential to continued participation in several physical activities throughout the lifespan (Stodden et al., 2014). However, several arguments can be presented to help understand our results: 1) stability skills (mainly dynamic stability) are considered critical to almost all movements (Gallahue et al., 2012); 2) the type of physical activities that children engage in varies with age, going from play-oriented activities during elementary school years (6-10 years old) to more organized sports in adolescence (Henderson, 2007) in which manipulative skills could not have an important role, but enhance several variables of HRF, for example gymnastics or running; 3) our manipulative skills did not demand high cardiovascular performance, so lower predictor values were found, especially in girls. Therefore, in the current study sample it appears that the development of coordination and control of multiple body segments is a more critical and a better discriminator of HRF in childhood and early adolescence than manipulative skills, and not just for early childhood as mentioned by Stodden and colleagues (2014). Nonetheless, and knowing that childhood is a critical period for the acquisition of MC and HRF, this data corroborate the notion that it is fundamental to promote both MC and HRF to benefit a healthy development of children.

Consistent with previous research (D'Hondt et al., 2010, 2014; Lopes, Stodden, et al., 2012), it was found that children's BMI and their MC is significantly negatively correlated. For example, D'Hondt and colleagues (2014) found that a child's BMI and MC can influence each other across time. However, some differences emerged between genders during growth, with the start of the decline in the strength of the association between BMI and MC starting earlier in boys (11-12 years-old) than in girls (13-14 years-old). The association remained nevertheless significant, even in the oldest age group. A previous study (Lopes, Stodden, et al., 2012) found a similar trend concerning the decrease in the strength of the association among older children. However, in that study the decline started at the same age in both sexes. It seems that the occurrence of puberty with different maturation patterns and intra- and inter-individual growth during this phase (Lopes, Stodden, et al., 2012) affects the relationship between BMI and MC in both sexes in various ways. The differences between the results of this study and the study of Lopes and colleagues (2012) might be related to the different methodologies used, since different instruments were used to assess MC in both studies. Lopes and colleagues (2012), in contrast to the present study, did not use manipulative skills to evaluate MC in their study, and the lack of this important variable could be a possible explanation for the difference in results. Additionally, as expected, locomotor skills displayed more negative associations with BMI since the increased body mass is detrimental to skills with greater body movement (*e.g.,* running). Contrary to previous finding (D' Hondt, Deforche, De Bourdeaudhuij, & Lenoir, 2009), manipulative skills showed only one significantly negative association with BMI. Therefore, higher body mass did not influence manipulative skills. However, the tasks that were used to assess manipulative skills can affect these results, since on these specific tasks higher proficiency could depend more on force production that on the coordination of high segmental velocities.

The present study extends the previous work developed by Stodden and colleagues (2014) and, to our knowledge, is the first study to analyse the relationship between MC and a composite HRF index across a large sample of childhood and adolescence, for both genders, using a validated instrument (Luz et al., 2015) that includes the three theoretical components proposed by Gallahue and colleagues (2012). However, the current study presents some limitations that should be mentioned. First, the cross-sectional design of the present study does not provide causal evidence with respect to the relationship between MC and other variables. To gain more insight in the direction of these relationships longitudinal and interventional studies should be conducted. The absence of maturational information (*e.g.*, sexual maturity, skeletal maturity) is another limitation. Biological maturation influences all variables mostly during the transition from childhood to adolescence; therefore, this variable should have been taken into consideration. Third, despite the good associations between handgrip task with both maximal upper and lower body strength (Milliken, Faigenbaum, Loud, & Westcott, 2008) other variables could have been included for this purpose, for example, vertical jump to assess leg strength.

5.5. Conclusion

Our results support the idea that MC and HRF are closely related in both boys and girls from 6 to 14 years. However, this association is variable across ages, contrary to previously suggested (Stodden et al., 2014). All MC components presented similar trend to the MC composite, with locomotor and stability skills being more frequently and strongly associated with the HRF index. Moreover, with the exception of the youngest age group and the oldest boys, inverse negative associations were found between MC and BMI in all groups. Interestingly, manipulative skills just presented one negative association with BMI.

Multiple regression analyses indicated that all motor variables were significant predictors of HRF with the locomotor component being the strongest predictor. Furthermore, separate analyses for boys and girls in each age group indicated different significant predictors according to age, Stability skills were the highest predictor in the older groups for both sexes. Therefore, it is possible that stability skills may present a key role in the relationship between MC and HRF across childhood and into adolescence. School-based interventions should consider the development of MC and its components as a key strategy to promote a healthy development across the lifespan.

5.6. References

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CHAPTER 6

CONCLUDING REMARKS

Concluding Remarks

In the preceding chapters we presented different studies related to motor competence in children and adolescents. The first part of this thesis focused on the assessment of motor competence and the second part aimed to investigate the behaviour of motor competence in children from 6 to 14 years of age, examining its relationship with health-related fitness.

Regarding the assessment of motor competence, in the systematic review we found that several instruments have been regularly used to evaluate motor competence. However, we could not find in the literature a practical and easy to administer instrument that included the three motor competence components (stability, locomotor and manipulative), and that was practical to be used by physical educations professionals. In an attempt to fill this gap, a large sample of children with ages between 6 and 14 years were assessed using nine well known quantitative motor tasks, divided into the three major components of MC, and structural equation modelling was used to find the best model to fit MC and its components. The final MC model was composed by the three latent factors (stability, locomotor and manipulative), each represented by two motor tasks. The model had very good overall fit indexes, and demonstrated a good structural and measurement reliability. We consider that the brief and easy to administer instrument that was proposed will be a valuable asset for physical education teachers who have to regularly assess their students. This instrument uses a quantitative approach with few motor tasks, which are representative of the major MC components, and it does not seem to have a celling effect. Moreover, a global composite score of MC may be obtained given the magnitude of the correlations between factors.

In the second part of this thesis (chapters 4 and 5), and using the model of MC proposed in chapter 3, we intended: to analyse the MC behaviour during growth in a large sample of children from 6 to 14 years; to investigate the differences, according to gender and age, in health related fitness variables amongst two groups with differentiated MC (*i.e.*, higher and lower MC); and to analyse the interrelationships among motor competence and its components with health related fitness. The findings indicated that: (i) boys presented better results than girls in motor competence and physical fitness variables; (ii) all MC variables increased in the older age groups in both genders; (iii) there were different growth rates for boys and girls, with girls presenting a higher slope between the younger groups and boys between the older groups, therefore sex differences increase from childhood to adolescence and older children become biologically more distinct; (iv) higher sex differences were found for manipulative skills; (v) the more proficient group showed better results in all health-related fitness variables; (vi) both MC proficiency groups presented significant different results across age groups with higher results in the older age groups for all HRF variables; furthermore, for cardiovascular fitness it seems that proficiency groups tend to become more different with growth; (vii) moderate to high correlations between MC and health-related fitness index were found in both sexes; (viii) for the entire sample, all motor competence components and age were significant predictors for HRF (R^2 = 75%); (ix) considering all MC components, the locomotor skills were the best predictors for HRF for the entire sample; (x) several predictors emerge across age groups, but stability skills were the highest predictor for both sexes in the older group.

Limitations

The MC model presented in chapter 3, indeed fills a gap in the literature and can be very useful to physical education professionals and to other sports professionals, however some limitations could be pointed:

- To achieve a more accurate representation of MC, a broader range of motor tests could have been included and tested in the model phase.
- To be consistent with the number of trials for each skill, the use of three trials could be more appropriate to select the best score. Therefore, in next studies this concern should be taken into consideration.
- We used demonstration (*i.e.*, visual guide) to explain the tasks. However, this proceeding can be harmful to low-skilled children since this type of information may provide them confusing information based on their current developmental level. Therefore, in future studies, we recommend the simple explanation of the tasks, letting the children perform at their specific developmental level.

In chapters 4 and 5 the MC model was used to better understand the MC behaviour and its relationship with HRF variables across several age groups and sex. Nevertheless, some limitations could be pointed:

- The cross-sectional design (in the last two chapters) makes it impossible to indicate causality between motor competence and other variables and to better understand the motor competence behaviour during growth and sexes. Therefore, longitudinal and interventional studies are needed.
- The absence of maturational information is another limitation. Biological maturation influences all variables mostly during the transition from childhood to adolescence; so, future

studies should consider the inclusion of variables that allow determining children's level of biological maturation.

- Also, we only used two tasks to evaluate health-related fitness measures, PACER (cardiovascular fitness) and the handgrip task (total body strength). However, other variables should have been included (*e.g.,* vertical jump and pushups) to a better analysis of this variable.
- A physical activity questionnaire was sent to the families but only a few responses were returned to the researcher, preventing the inclusion of this important variable in the analysis.

Implications

This study developed a brief and easy to administer instrument representative of MC with the three MC components, which can be used by several professionals to objectively monitor MC in several contexts. The results in chapter 4 highlight the importance to provide more and adequate motor experiences especially to girls since sex differences across age groups were found since early ages. Moreover, it is necessary to make intervention or rehabilitation programs targeting the low motor proficiency children, since the results showed that this group presented always-significant low results in health-related fitness. In chapter 5, we examined the relationship between MC and HRF and moderate to higher correlations between MC and health-related fitness variables emerged in this study; so more childhood programs to enhance MC should exist to promote healthy lifestyles. Although, the findings suggest that stability skills may present a key role in the relationship between MC and HRF across childhood and into adolescence, the MC programs should include the three components of MC, since all motor components were significant predictors of health-related fitness index. In general, children might benefit from motor skills training and this practice should be integrated into the PE curriculum activities, which are the ideal environment to provide opportunities and experiences according to children's capabilities.

Suggestions for Future Research

Our model included children from 6 to 14 years old of both genders and it is possible that the results might even have a better adjustment if separate groups of age and gender are considered. Future investigations should take into consideration age and gender. Also, additional research using our MC model is vital for a better understanding of MC normative development over childhood and adolescence. Regarding the better understanding of MC behaviour and its relationship with HRF variables, future research should include: 1) variables that allow determining children's level of biological maturation; 2) older ages (adolescent and young adult); and 3) more HRF variables (*e.g*., pushups and vertical jump). Other associations should be explored using our MC model, namely physical activity and perceived motor competence. Also, future investigations should analyse the relationship with cognition using latent variables and structural equation modelling to further analyse the possible directional relation between MC and executive functions, with processing speed as mediator (Luz, Rodrigues, & Cordovil, 2014). In addition, longitudinal and interventional studies are needed to be able to better understand of the relationship between MC and HRF considering the individual trajectories of MC development. Moreover, cross-cultural differences in MC (using our model) should be investigated to a better understanding of children's motor competence worldwide. Additional research should also investigate the convergent and discriminant validity between our MC assessment and other forms of measurement.

We strongly believe that our MC model, using the three theoretical components, developed in this thesis fills an important gap in the literature and can be helpful for many sport professionals. The findings concerning MC behaviour and its relationship with HRF variables (chapter 4 and 5) produce additional and new important knowledge to the literature.